

Worldwide Diagnostic Reference Levels for Single Photon Emission Computed Tomography Myocardial Perfusion Imaging: Findings from the IAEA Nuclear Cardiology Protocols Study (INCAPS)

Brief title: Diagnostic Reference Levels for SPECT MPI

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STRUCTURED ABSTRACT

Objectives: To establish worldwide and regional diagnostic reference levels (DRLs) and achievable administered activities (AAAs) for SPECT MPI.

Background: Reference levels serve as radiation dose benchmarks to compare individual laboratories against aggregated data, helping to identify sites in greatest need of dose reduction interventions. DRLs for SPECT myocardial perfusion imaging (MPI) have previously been derived from national or regional registries. To date there have been no multi-regional reports of DRLs for SPECT MPI from a single standardized dataset.

Methods: Data were submitted voluntarily to the International Atomic Energy Agency Nuclear Cardiology Protocols Study (INCAPS), a cross-sectional, multinational registry of MPI protocols. 7,103 studies were included. DRLs and AAAs were calculated by protocol for each world region and for aggregated worldwide data.

Results: The aggregated worldwide DRLs for rest/stress or stress/rest studies employing Tc-99m labelled radiopharmaceuticals were 11.2 mCi (1st dose) and 32.0 mCi (2nd dose) for 1-day protocols, and 23.0 mCi (1st dose) and 24.0 mCi (2nd dose) for multi-day protocols.

Corresponding AAAs were 10.1 mCi (1st dose) and 28.0 mCi (2nd dose) for 1-day protocols, and 17.8 mCi (1st dose) and 18.7 mCi (2nd dose) for multi-day protocols. For stress-only Tc-99m studies, the worldwide DRL and AAA were 18.0 mCi and 12.5 mCi, respectively. Stress-first imaging was used in 26-92% of regional studies except in North America where it was used in just 7% of cases. Significant differences in DRLs and AAAs were observed between regions.

Conclusions: This study reports reference levels for SPECT MPI for each major world region from one of the largest international registries of clinical MPI studies. Regional DRLs may be useful in establishing or revising guidelines or simply comparing individual laboratory protocols

to regional trends. Organizations should continue to focus on establishing standardized reporting methods, to improve the validity and comparability of regional DRLs.

KEY WORDS:

Diagnostic reference level, SPECT myocardial perfusion imaging, administered activity, radiation dose reduction

CONDENSED ABSTRACT

Drawn from worldwide data from INCAPS, one of the largest international registries of clinical MPI studies, this report constitutes the first multi-regional report of diagnostic reference levels (DRLs) and achievable administered activities (AAA) for SPECT MPI. Significant differences in DRLs and AAAs were observed between world regions, owing to major variations in regional practices. This heterogeneity highlights the need to establish standardized international reporting methods in order to improve the validity and comparability of regional DRLs. Regional reference levels may serve an important role in both the evaluation of international practice trends and the optimization of future clinical guidelines.

ABBREVIATIONS:

AAA = achievable administered activity; DRL = diagnostic reference level; IAEA = International Atomic Energy Agency; ICRP = international commission on radiological protection; INCAPS = IAEA Nuclear Cardiology Protocols Study; MBq = megabecquerel; mCi = millicurie; MPI = myocardial perfusion imaging; SPECT = single-photon emission computed tomography; Tc-99m = technetium-99m; Tl-201 = thallium-201

INTRODUCTION

Myocardial perfusion imaging (MPI) is an effective non-invasive method to diagnose and risk-stratify patients with coronary artery disease, but it may also account for a fifth of the total burden of radiation to the United States (U.S.) population from medical imaging.(1-3) The rising utilization of medical imaging in recent decades has ignited concerns over the effects of population exposure to ionizing radiation.(3-6) In response, numerous organizations have published guidelines to define best practices and detailed patient selection criteria to optimize dose reduction.(7-14) Recent data have shown that the majority of U.S. facilities continue to operate above dose levels that could be attained through compliance with guideline recommendations, which suggests that adherence to best practices may be sub-optimal.(15,16)

Another method of reducing radiation exposure is to identify facilities where patient doses are unusually high, such that implementing targeted dose reduction strategies would have the greatest impact. This idea was first suggested by the International Commission on Radiological Protection (ICRP) in its Publication 60 (1991), which introduced the concept of “investigational levels” to be set for common diagnostic procedures.(17) This term later became known as the diagnostic reference level (DRL) in ICRP Publication 73 (1996).(18) In both diagnostic radiology and nuclear medicine, DRLs represent a benchmark, above which outliers may be identified for closer examination of practices and protocols.(18-22) DRLs can be established at a local or national levels and should ideally be derived from distributions of actual patient examinations.(20) The implementation of DRLs as a dose reduction strategy is widely endorsed by professional societies and national agencies for radiological protection (7-9,11,14,22-25), and required by the International Safety Standards.(26,27) More recently, the concept of achievable administered activity (AAA), which corresponds to the median (50th

percentile) of a distribution of doses, has emerged as a target for further dose optimization in facilities that fall below the DRL.(7,19)

As one of the largest contributors to medical radiation exposure, it is vital to establish DRLs for SPECT MPI dose optimization in every world region. Unfortunately, efforts to derive and utilize DRLs in cardiology and nuclear medicine lag behind other fields, with a limited availability of quality data.(7,22) Furthermore, there is no standard methodology for reporting DRLs for SPECT MPI between regions, or within a region, making efforts to compare DRLs challenging and imprecise. The European Commission observed that the comparison of DRLs for myocardial perfusion studies was especially difficult due to differences in the reporting of protocols between European countries.(8) Publication 135 of the ICRP states that “it is difficult to compare administered activities without knowing the precise protocol used.”(19) Alkhybari et al. published a systematic review of DRL methods for positron emission tomography-computed tomography (PET/CT) and SPECT/CT in which they identified major regional and national discrepancies in the methods used to calculate and report DRLs and recommended more robust standards to improve the comparability of international reference levels.(28)

In this analysis, we calculate and compare regional reference levels (DRLs and AAAs) for SPECT MPI using a single international registry of MPI studies. The International Atomic Energy Agency (IAEA) coordinated a cross-sectional study to collect data on MPI from facilities around the globe called the IAEA Nuclear Cardiology Protocols Study (INCAPS). Drawn from worldwide INCAPS data, this report constitutes the first multi-regional report of reference levels for SPECT MPI.

METHODS

Methods of the INCAPS study have been described in detail previously.⁽¹⁵⁾ A cross-sectional study was conducted in which facilities performing nuclear MPI were asked to report details of every patient scan performed during a single week from March 18 to April 22, 2013. Facilities were identified through registration with the IAEA as well as other local and international professional organizations. Participation in the registry was on a voluntary basis. Studies utilizing positron emission tomography (PET), studies that performed rest-only imaging, and studies performed on patients < 18 yrs of age were excluded from this analysis.

Regions were defined as Africa, Asia, Europe, Latin America, North America, and Oceania. Registry data in this analysis included information about patient demographics, facility practice setting, study protocol, radiopharmaceuticals, and administered activity. Study protocols were differentiated by sequence and timing. Protocol sequences were defined as stress-rest (stress imaging followed by rest imaging), rest-stress (rest imaging followed by stress imaging), and stress-only. Studies were further distinguished by study timing (1-day vs. multi-day), and dose (first dose vs. second dose). Radioisotopes used in MPI studies were technetium-99m (Tc-99m), thallium-201 (Tl-201), or dual isotope studies (Tl-201 in the first dose and Tc-99m in the second dose). Tc-99m rest-stress and stress-rest studies were grouped together and we did not distinguish between Tc-99m radiotracers (tetrofosmin versus sestamibi) in this analysis.

The DRL was calculated as the 75th percentile of the distribution of administered activities in each individual category, while the AAA was calculated as the median of the distribution. Values at the tail ends of each distribution were included in the analysis. All statistical analyses and calculations were performed using Stata version 15.1 and Microsoft Excel 2013. The study was approved by the Columbia University Institutional Review Board, which declared it exempt from the requirements of US federal regulations for the protection of

human subjects (45 CFR 46) since the study collected no individually identifiable health information.

RESULTS

7,911 MPI studies were submitted to the INCAPS database of which 474 PET studies, 299 rest-only studies, two pediatric studies, and 33 SPECT cases with incomplete data were excluded, leaving a total of 7,103 SPECT MPI studies for this analysis.

Demographics

Demographic data are summarized in Table 1. Studies were submitted from 298 individual facilities in 65 countries. Europe contributed the greatest number of total studies (31%) followed by North America (25%), Asia (19%), Latin America (15%), Oceania (6%), and Africa (5%). North America had the greatest ratio of studies per laboratory (33) whereas Oceania had the lowest ratio (13). More studies were performed on men in all regions (range 55-61%). The most common facility-type was hospital mixed inpatient/outpatient (65%). The remainder of studies were performed in outpatient imaging-only facilities (15%), outpatient facilities with physician practices (13%), or either a hospital inpatient (4%) or hospital outpatient (4%) setting.

Protocols and Radioisotopes

Table 1 also summarizes the breakdown of specific protocols and radioisotopes for each region, whereas Table 2 shows the number of studies for each calculated AAA and DRL category. Rest-stress protocols were utilized in 90% of North American cases, while each of the remaining protocols were used in $\leq 3\%$ of cases. Stress-first imaging (e.g. stress-rest or stress-

only) was used in more than a quarter of studies in every region (range 26-92%) except North America where it was used in only 7% of cases. Stress-only studies accounted one third of all studies from Africa and one fifth from Europe and Asia. Tc-99m-labelled tracers were used in greater than 94% of studies in all regions except for Asia where 20% of studies were performed using either Tl-201 or dual isotope protocols.

DRLs and AAAs

DRLs (Table 3) and AAAs (Table 4) are summarized for each protocol by world region. The aggregated worldwide DRLs for studies employing Tc-99m labelled radiopharmaceuticals were 42.7 mCi (regional range 30.0-46.0) for 1-day rest-stress or stress-rest, 46.0 mCi (regional range 37.8-64.3) for multi-day rest-stress or stress-rest, and 18.0 mCi (regional range 9.7-24.0) for stress-only studies. The aggregated worldwide AAAs for studies employing Tc-99m labelled radiopharmaceuticals were 39.1 mCi (regional range 23.0-42.2) for 1-day rest-stress or stress-rest, 36.0 mCi (regional range 32.7-61.6) for multi-day rest-stress or stress-rest, and 12.5 mCi (regional range 7.2-20.0) for stress-only studies.

Wide ranges for DRLs and AAAs were observed between regions for every protocol. The ratio of highest to lowest regional DRL ranged from a factor of 1.5 for 1-day Tc-99m rest-stress or stress-rest protocols to 2.5 for Tc-99m stress-only protocols. The lowest DRLs for Tc-99m studies were observed in stress-only protocols, where Oceania had the lowest DRL of just 9.7 mCi and Africa and Latin America were the highest at 24.0 mCi. The DRLs and AAAs for 1-day Tc-99m stress-rest or rest-stress protocols were less than the DRLs and AAAs for multi-day protocols in every region. However, the aggregated worldwide AAA for 1-day Tc-99m studies was greater than the AAA for multi-day studies owing to differences in the proportion of studies

contributed by each region for each protocol. For example, North America, which had the highest AAAs, comprised 40% of all 1-day rest-stress or stress-rest studies versus only 6% of all multi-day studies, whereas Europe, which had the lowest AAAs, comprised 21% of 1-day studies and 45% of the multi-day studies.

DISCUSSION

This report establishes worldwide and regional DRLs and AAAs for SPECT MPI from the INCAPS data. We observed wide ranges for DRLs and AAAs for nearly every protocol, owing to significant variations in regional practices. Comparing reference levels from our study to previously published literature was challenging due to limited available data and major differences in methods of data collection, analysis, and reporting between regions. This heterogeneity highlights the need for greater international standardization of methods for establishing and reporting reference levels for SPECT MPI. Regional reference levels may serve an important role in both the evaluation of international practice trends and the optimization of future clinical guidelines.

Recent DRLs for SPECT MPI for U.S. laboratories were published by Becker et al. (2016) and in Report 172 from the NCRP (2012).(7,29) DRLs for Europe are published in Report 180 by the European Commission (2014) and for Oceania by the Australian Radiation Protection and Nuclear Safety Agency (ARPNSA, 2017).(8,30) At present, no regional DRLs for SPECT MPI have been established for Africa, Asia, or South America.

We found that DRLs published previously were generally in accordance with the values published here. However, direct comparisons were not always possible given significant differences in the methods of reporting DRLs between regions, owing in part to regional

variations of practices, protocols, and data sources. For example, Becker and colleagues published U.S. DRLs for SPECT MPI using 7,311 studies from the American College of Radiology (ACR) accreditation data.(29) Ninety five percent of cases in their study were rest-stress protocols. Rest-stress protocols also comprised 93% of North American cases in our study, but they represented only 46% of cases worldwide. In recent years, several U.S. reports have demonstrated comparable diagnostic performance and significant reductions in patient radiation exposure using “stress-first” imaging, whereby a normal stress study may obviate the need for subsequent rest imaging.(31-35) The American Society of Nuclear Cardiology (ASNC) published updated guidelines in 2018 which now strongly recommend the use of stress-first imaging where feasible.(24) Our data revealed that stress-first or stress-only protocols were used just 7% of NA studies compared to 85% of European studies.

Additionally, we observed that reference levels for stress-only studies tended to fall between DRLs for the first dose of 1-day and multi-day Tc-99m studies. For instance, the regional DRL for North American stress-only protocols was 18.8 mCi (696 MBq) versus 11.0 mCi (407 MBq) for the first dose of 1-day Tc-99m stress-rest protocols and 32.4 mCi (1199 MBq) for the first dose of multi-day protocols. This difference is likely due to the fact that stress-only protocols resemble a combination of both low dose and high dose initial stress studies. This finding was consistent across almost every region. In light of recent evidence and guidelines, it would be desirable for more North American laboratories to shift towards stress-first imaging, and differentiating DRLs by protocol sequence could help to further standardize international reporting and facilitate comparability of DRLs between regions.

Different methods of calculating and reporting DRLs may also impact the interpretation of variation between reports. NCRP Report 172 lists U.S. reference levels for SPECT MPI based

on a 2010 survey where facilities were asked to report the minimum and maximum administered activities for various study protocols.(7) This report uses the term “reference level” rather than DRL for non-x-ray examinations, including nuclear medicine. Reference levels are listed for the 75th percentile of the distribution of minimum activities and the 75th percentile of the distribution of maximum activities for each protocol, resulting in a wide range of values that is difficult to compare with existing data. For example, the reference levels (minimum-maximum) for rest-stress Tc-99m-sestamibi studies were 14-31 mCi (rest) and 26-39 mCi (stress).(7) The lower end of the rest dose reference level range (i.e., 14 mCi) is greater than the DRL of 11 mCi from our data and 11.5 mCi reported in Becker et al. This difference may be due to the fact that DRLs were not reported separately for 1-day and multi-day protocols. We found that DRLs for 1-day Tc-99m studies were lower than DRLs for multi-day studies in every region. Alessio and colleagues point out that artificially inflated DRLs would allow laboratories to fall below the 75th percentile who would otherwise benefit from closer examination for radiation improvement strategies.(22)

Similarly, European MPI data, published by the European Commission in Report 180, are limited to only three DRLs (Tl-201, Tc-99m tetrofosmin, and Tc-99m sestamibi).(8) They report a 5-fold difference between the minimum and maximum DRL range for Tc-99m studies alone (300 – 1500 MBq). The authors comment that the comparison of DRLs for myocardial perfusion studies was especially difficult due to differences in the reporting of protocols between European countries. Through a standardized worldwide dataset, INCAPS has enabled more granular, protocol-specific analyses and comparisons of regional DRLs. Researchers and organizations reporting DRLs should continue to focus on establishing standardized calculation and reporting methods in order to improve the comparability and clinical utility of regional DRLs.

We acknowledge that this study is not without limitations. First, regional participation in INCAPS was variable, and the extent to which the facilities that participated in INCAPS are representative of all cardiac nuclear imaging centers in each region is unknown. Despite this, INCAPS is one of the largest worldwide registries of SPECT MPI data, and it is the first regional data registry in Asia, Africa, and South America, serving as a baseline to compare future studies. Relatedly, voluntary participation in INCAPS raises the potential for volunteer bias (e.g. laboratories with higher doses or worse adherence to best practices may have been less inclined to participate), which might cause DRLs to be underestimated in some cases. However, where comparable, DRLs were generally in agreement with previously published data.(29) Laboratories also submitted data during a limited time period which may not precisely reflect the variety and distribution of scans being performed in each facility, although, this is likely offset by sampling multiple centers in each region.

We also recognize that since the INCAPS implementation, which was carried out in 2013, changes in hardware, software and clinical protocols have been put into effect in many facilities worldwide. In view of this, the IAEA will lead the implementation of INCPAS II beginning in 2020. INCAPS II is expected to provide updated data on global and regional diagnostic DRLs and AAAs for SPECT MPI.

INCAPS offers a unique opportunity to establish DRLs from a worldwide registry dedicated to MPI, enabling the first multi-regional comparison of DRLs from a single standardized dataset. We observed significant variations in protocols, data collection methods, and analyses between regional studies and guidelines, which affected how DRLs were calculated and reported and made inter-regional comparisons of DRLs more challenging. INCAPS ameliorates some of these barriers by standardizing the analysis and reporting of regional data,

enabling us to report more granular, protocol-specific details that are consistent between regions. As a cross-sectional analysis of actual patients' scans, the dataset may also be more representative of the variety, distribution, and frequency of scans seen in the clinical setting. The IAEA and partners are actively working on the next iteration of INCAPS enabling DRLs to be re-evaluated longitudinally. Worldwide and regional DRLs may be useful in establishing or revising guidelines or simply comparing laboratory protocols to regional trends. Efforts to reduce radiation exposure in SPECT MPI should continue through standardization of protocols and adherence to best practices.

PERSPECTIVES:

Clinical competencies: this report constitutes the first multi-regional report of reference levels for SPECT MPI, which may aid in the evaluation international practice trends and the optimization of future clinical guidelines to further reduce population radiation exposure.

Translational outlook: by using a single international registry, the analysis and reporting of regional reference levels can be more easily standardized, improving their comparability both at present and longitudinally in potential future studies.

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Table 1. Regional demographic data for SPECT MPI studies

	Africa	Asia	Europe	Latin America	North America	Oceania	Worldwide
Studies, n (%)[*]	330 (5%)	1345 (19%)	2187 (31%)	1055 (15%)	1754 (25%)	432 (6%)	7103
% Male	60%	61%	61%	58%	57%	55%	59%
Countries	6	18	27	10	2	2	65
Labs	12	69	93	36	54	34	298
Facility-type, n (%)[†]							
Hospital inpt	-	71 (5%)	66 (3%)	57 (5%)	32 (2%)	29 (7%)	255 (4%)
Hospital opt	25 (8%)	-	45 (2%)	-	187 (11%)	-	257 (4%)
Hospital mixed inpt/opt	163 (49%)	1259 (94%)	1659 (76%)	522 (49%)	778 (44%)	269 (62%)	4650 (65%)
Opt w/ physician practices	70 (21%)	15 (1%)	31 (1%)	181 (17%)	529 (30%)	83 (19%)	909 (13%)
Opt imaging-only	72 (22%)	-	386 (18%)	295 (28%)	228 (13%)	51 (12%)	1032 (15%)
Protocol, n (%)[†]							
Stress-rest (1-day)	48 (15%)	391 (29%)	797 (36%)	212 (20%)	22 (1%)	56 (13%)	1526 (21%)
Stress-rest (multi-day)	145 (44%)	238 (18%)	599 (27%)	166 (16%)	57 (3%)	2 (0%)	1207 (17%)
Rest-stress (1-day)	8 (2%)	397 (30%)	62 (3%)	307 (29%)	1571 (90%)	284 (66%)	2629 (37%)
Rest-stress (multi-day)	20 (6%)	47 (3%)	271 (12%)	316 (30%)	52 (3%)	35 (8%)	741 (10%)
Stress-only	109 (33%)	272 (20%)	458 (21%)	54 (5%)	52 (3%)	55 (13%)	1000 (14%)
Radioisotope, n (%)[†]							
Tc-99m	330 (100%)	1071 (80%)	2123 (97%)	1030 (98%)	1730 (99%)	404 (94%)	6688 (94%)
Tl-201	-	169 (13%)	58 (3%)	14 (1%)	-	20 (5%)	261 (4%)
Dual Isotope	-	105 (8%)	6 (0%)	11 (1%)	24 (1%)	8 (2%)	154 (2%)

*percentage of row total

†percentage of column total

inpt = inpatient; opt = outpatient; Tc = technetium; Tl = thallium;

Table 2. Number of SPECT MPI protocols submitted by each region

Protocol	Africa	Asia	Europe	Latin America	North America	Oceania	Worldwide
Tc-99m rest/stress or stress/rest, 1 day	56	664	832	495	1569	327	3943
Tc-99m rest/stress or stress/rest, 2 days	165	285	870	482	109	37	1948
Tc-99m stress only	109	122	421	53	52	40	797
Tl-201, 1 injection	-	150	37	1	-	15	203
Tl-201, 2 injections	-	19	21	13	-	5	58
Dual Isotope	-	105	6	11	24	8	154
	330	1345	2187	1055	1754	432	7103

Table 3. Worldwide and regional DRLs for SPECT MPI from the INCAPS registry

		Administered Activity, mCi (MBq)						
		Africa	Asia	Europe	Latin America	North America	Oceania	Worldwide
Tc-99m rest-stress or stress-rest, 1 day	1st dose	11.0 (407)	10.9 (403)	13.3 (492)	15.0 (555)	11.0 (407)	10.1 (374)	11.2 (414)
	2nd dose	20.0 (740)	30.0 (1110)	22.0 (814)	32.0 (1184)	33.9 (1254)	29.7 (1099)	32.0 (1184)
Tc-99m rest-stress or stress-rest, 2 days	1st dose	27.0 (999)	24.5 (905)	19.0 (703)	25.0 (925)	32.4 (1199)	22.6 (836)	23.0 (851)
	2nd dose	27.0 (999)	25.0 (925)	19.1 (706)	25.0 (925)	32.4 (1199)	24.8 (918)	24.0 (888)
Tc-99m stress only	1st dose	24.0 (888)	12.6 (466)	18.0 (666)	24.0 (888)	18.8 (696)	9.7 (359)	18.0 (666)
Tl-201, 1 injection	1st dose	-	3.2 (118)	3.0 (110)	4.0 (148)	-	2.0 (75)	3.2 (117)
Tl-201, 2 injections	1st dose	-	3.0 (111)	2.2 (83)	3.0 (111)	-	1.5 (57)	3.0 (111)
	2nd dose	-	1.2 (44)	1.1 (41)	1.0 (37)	-	0.5 (19)	1.1 (41)
Dual Isotope	1st dose	-	3.0 (111)	3.8 (140)	3.0 (111)	3.0 (112)	2.2 (80)	3.0 (111)
	2nd dose	-	22.5 (833)	21.6 (800)	20.0 (740)	34.0 (1258)	13.8 (511)	25.0 (925)

DRL = diagnostic reference level; INCAPS = IAEA Nuclear Cardiology Protocols Study; MBq = megabecquerels; mCi = millicuries; Tc = technetium; Tl = thallium

Table 4. Worldwide and regional AAAs for SPECT MPI from the INCAPS registry

		Administered Activity, mCi (MBq)						
		Africa	Asia	Europe	Latin America	North America	Oceania	Worldwide
Tc-99m rest-stress or stress-rest, 1 day	1st dose	10.0 (370)	10.0 (370)	9.3 (344)	11.0 (407)	10.5 (389)	8.6 (318)	10.1 (374)
	2nd dose	17.0 (629)	27.8 (1029)	19.2 (710)	30.0 (1110)	31.8 (1178)	27.0 (1000)	28.0 (1036)
Tc-99m rest-stress or stress-rest, 2 days	1st dose	25.0 (925)	21.0 (777)	16.2 (600)	20.0 (740)	30.9 (1143)	21.9 (810)	17.8 (657)
	2nd dose	26.0 (962)	21.0 (777)	16.3 (603)	20.0 (740)	31.1 (1151)	24.1 (892)	18.7 (690)
Tc-99m stress only	1st dose	10.0 (370)	12.5 (463)	12.9 (477)	20.0 (740)	15.3 (566)	7.2 (265)	12.5 (463)
Tl-201, 1 injection	1st dose	-	3.1 (114)	2.8 (104)	4.0 (148)	-	2.0 (74)	3.0 (111)
Tl-201, 2 injections	1st dose	-	2.9 (106)	2.2 (81)	3.0 (111)	-	1.5 (55)	2.5 (93)
	2nd dose	-	1.1 (40)	1.1 (40)	1.0 (37)	-	0.5 (19)	1.0 (38)
Dual Isotope	1st dose	-	3.0 (111)	3.5 (128)	3.0 (111)	3.0 (111)	2.0 (75)	3.0 (111)
	2nd dose	-	21.0 (777)	21.6 (800)	20.0 (740)	30.5 (1129)	13.2 (490)	21.5 (796)

AAA = achievable administered activity; INCAPS = IAEA Nuclear Cardiology Protocols Study; MBq = megabecquerels; mCi = millicuries; Tc = technetium; Tl = thallium;

Appendix

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