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ORIGINAL ARTICLE

Minimal rest activity for SPECT myocardial perfusion imaging in a one-day stress-first protocol

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Abstract

Purpose Guidelines propose different rest–stress activity ratios (RSAR) for one-day stress-first SPECT myocardial perfusion imaging (MPI), but evidence is limited. Our aim was to determine and validate the minimal RSAR resulting in the same diagnostic outcome in one-day stress-first SPECT MPI.

Methods Forty-seven patients referred for rest after stress CZT-SPECT/CT MPI were prospectively included. Rest acquisitions were performed 3 h after stress. In addition to the stress and rest acquisitions, the first 22 patients underwent an additional acquisition prior to the rest injection to determine the remaining stress activity. Next, we simulated six RSARs varying from 1.0 to 3.5 in both patients and a phantom and compared the images to those using the reference RSAR of 4.0. Differences in summed difference score (SDS) >2 or ischemic defect interpretation were considered to significantly influence diagnostic outcome. After deriving the minimal RSAR, it was validated in 25 additional patients by comparing it to a RSAR of 4.0.

Results After 3 h only 26% of the stress activity was still present in the myocardium. SDS differences >2 were found in one (4%) patient using RSAR of 3.5, 2.5 and 2.0, in three (12%) using 1.5 and in five (20%) using SRAR of 1.0. These results were consistent with the phantom study showing SDS differences >2 for RSARs ≤1.5 and with the visual interpretation which showed an increased number of deviating scans for RSAR 1.0. Validating the RSAR of 2.0 resulted in a different SDS in one patient (SDS of 30 versus 11). Moreover, two scans were interpreted as ischemic instead of normal when using RSAR 2.0 and in two other scans the opposite was the case.

Conclusions A RSAR of 2.0 in one-day stress-first MPI SPECT seems sufficient to obtain accurate diagnostic outcomes and is therefore recommended to reduce radiation exposure.

Keywords Radiation dose reduction · Stress-only · Myocardial perfusion imaging: SPECT · One-day protocol · Activity

Abbreviations

CT	Computer tomography
iTPD	Ischemic total perfusion deficit
MPI	Myocardial perfusion imaging
SDS	Summed difference score
SPECT	Single photon emission computed tomography
RSAR	Rest-stress activity ratio
TPD	Total perfusion deficit

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Introduction

For patients with suspected stable coronary artery disease it is recommended to test non-invasively for ischemia prior to invasive coronary angiography [1, 2]. For this purpose, several diagnostic modalities are available of which myocardial perfusion imaging (MPI) with single photon emission-computed tomography (SPECT) is the most validated non-invasive method [3]. SPECT MPI using a one-day stress-only or stress-optional-rest protocol is growing in use. Adoption of such a protocol majorly reduces the radiation exposure while

maintaining the diagnostic accuracy and improving laboratory efficiency [4].

Several studies determined the minimal tracer activity for stress MPI while maintaining the diagnostic accuracy to further limit the radiation exposure [5–7]. Although 66–75% of the total radiation dose in a one-day stress-first protocol is due to the rest activity, the minimal tracer activity needed for the rest study remains fairly unknown [4, 8]. Guidelines currently suggest to administer three to four times the stress activity for the rest study with a delay of 0.5 to 2 h between both administrations but evidence is limited [9–12]. The rest–stress activity ratio (RSAR) varies in clinical practice and only 51% of the non-US laboratories apply a RSAR of 3.0 or more [8]. Yet a rest activity which is too low may induce shine-through or crosstalk of stress perfusion defects leading to underestimation of defect reversibility [8, 11]. The aim of this study was to determine and validate the minimal RSAR required to prevent the occurrence of shine-through effects and, hence, resulting in similar diagnostic outcome using a one-day stress first SPECT MPI protocol.

Method

Study population

We prospectively included 47 patients who underwent clinically indicated cadmium-zinc-telluride (CZT)-SPECT/CT stress–rest MPI (Discovery NM 570c, GE Healthcare) using a one-day stress-optional-rest protocol. The first 22 patients were consecutively included in the first part of this study where we derived the minimal required RSAR (further referred to as group A). An additional 25 patients were consecutively included to validate the minimal RSAR (further referred to as group B). The study protocol was approved by the local institutional ethics committee and written informed consent was obtained from each study participant.

Patient preparation and image acquisition

Patients were requested not to use any nicotine or caffeine containing beverages for 24 h and to discontinue persantin for 48 h prior to scanning. Pharmacological stress was induced by intravenous administration of adenosine (140 μg/kg/min for 6 min) or regadenoson (5 ml with 400 μg for 15 s followed by a saline flush). A fixed tracer activity of 200 MBq Tc-99 m tetrofosmin was administered intravenously at peak stress in group A [6, 13]. Patients were requested to consume at least half a chocolate bar and to drink three cups of water post injection to reduce sub-diaphragmatic activity uptake and improve image quality of the inferior wall.

Patients were scanned in supine position, with their arms placed above their heads. Patient's chest was positioned close to the SPECT detectors, with the heart in the center of the field of view, assisted by using real-time persistence imaging. Images were acquired with a 20% symmetrical energy window centered at 140 keV. Attenuation correction was not used in this study to prevent reproducibility errors [14]. Stress imaging was performed 45–60 min post injection using a patient-specific scan time of 5.4 s/kg [6, 13].

Three hours post stress-activity administration, patients in group A were scanned prior to administration of the rest activity, further referred by as the pre-rest scan, as shown in Fig. 1. This acquisition was acquired using a patient-specific scan time of 5.4 s/kg which allowed us to determine remaining stress-activity that may cause shine-through effects in the rest scan [6, 13]. After the pre-rest scan, we marked the patient's position with a waterproof marker on the patient's chest in relation to the scanner-mounted positioning lasers enabling us to exactly reposition the patient when acquiring the rest study. Next, 800 MBq Tc-99 m tetrofosmin was intravenously administered. Rest imaging was performed 45–75 min post injection. Rest acquisition was performed using a scan time of 2.8 s/kg.

Patients in group B received two rest activity administrations, each followed by a SPECT acquisition. We injected the first rest activity administration of 400 MBq at least 3 h after the stress activity administration. The minimal RSAR of 2.0 as determined in the first part of our study was simulated with this activity. After the first rest scan, patients were again administered with 400 MBq (remaining original rest activity) to obtain a rest scan with a RSAR of 4. Both rest acquisitions were performed 40–60 min post injection using a scan time of 2.8 s/kg.

Reconstruction and image assessment

All acquired projection data were reconstructed using an iterative dedicated reconstruction algorithm with maximum-likelihood expectation maximization (Myovation, GE Healthcare). Each image was automatically normalized to the maximum peak activity and the segmental uptake values were presented as the percentage of the maximum myocardial regional uptake [15–17]. The total perfusion deficit (TPD) and summed stress, rest and difference scores (SSS, SRS and SDS) were automatically computed (QPS 2007, Cedars-Senai Medical Center) to account for both the defect severity and extent. TPD was calculated as the percentage of segments below a predefined uniform average deviation threshold, as explained in detail by Berman et al. [18]. We derived the ischemic TPD (iTPD) by subtracting the TPD in stress from the TPD in rest. Images were displayed in the

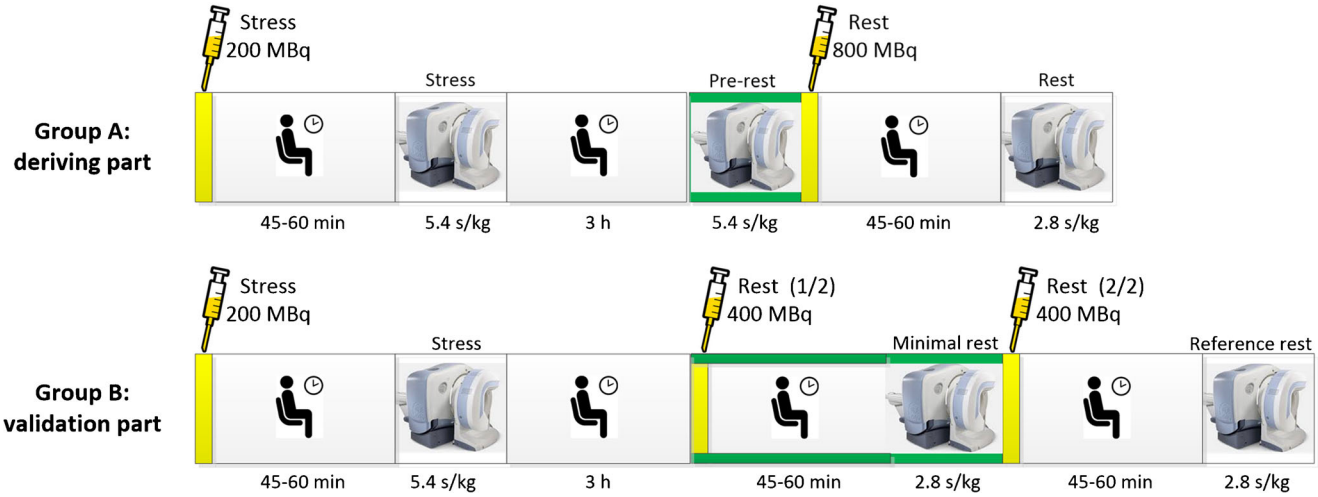

Fig. 1 Overview of the patient imaging protocols for the deriving part (group A) and validation part (group B). The *green bars* indicate the additional actions associated with this study

traditional short, vertical long and horizontal long axes and bullseye plot using a color scale.

Washout

The total number of photon counts measured by all 19 stationary pinhole detectors of the CZT-SPECT system were determined for the stress, the pre-rest and the rest scans in Group A. The total washout, defined as the percentage of remaining activity prior to the rest injection, was calculated by dividing the number of counts acquired in the pre-rest scan with that from the stress scan. The biological washout was determined by correcting the total washout for radioactive decay. Patients with gastro-intestinal activity overlapping the myocardial activity were excluded when determining the biological washout. Next, we derived the photon count ratio between the remaining activity from the stress injection in the pre-rest scan and the rest injection after compensating for the time delay and radioactive decay between the pre-rest and rest scans:

$$CountRatio = \frac{K \cdot Countrate_{rest} - Countrate_{prerest} \cdot 0.5^{\left(\frac{T}{T_{1/2}}\right)}}{Countrate_{prerest}} \quad (1)$$

with

$$K = \frac{RSAR_{sim}}{RSAR_{org}} \quad (2)$$

Here, $countrate_{rest}$ and $countrate_{prerest}$ are the count rates as measured in the rest and pre-rest scans, respectively; T is the time delay between the pre-rest and rest scan; and $T_{1/2}$ the half life time of Tc-99 m (6 h). The CountRatio was determined for multiple SRARs in each patient. $RSAR_{org}$ is the original RSAR of 4.0, and $RSAR_{sim}$ is the simulated RSAR which we varied from 1.0 to 4.0.

Phantom study

We performed a phantom study to simulate the effect of different RSARs: 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 on the detectability of ischemia. We filled a phantom simulating the myocardium (Dynamic Insert ECT/CAR/I, Data Spectrum Corporation) with 15 MBq Tc-99 m and acquired two scans: one without defects, $Scan_{rest}$, and one with defects, $Scan_{stress}$. Defects in the stress scan were simulated by placing two solid defects inside the cardiac insert in the antero-lateral wall (100% defect) and the inferior-septal wall (50% defect). The total scan time for the stress scan T_{stress} was 115 s to obtain a similar number of measured photon counts as in patients. Next, we created the rest simulations with shine-through effect from the stress scan for the seven different RSARs. We therefore summed a part of $Scan_{stress}$ with $Scan_{rest}$ while varying the scan time of $Scan_{rest}$ to simulate different count ratios between stress and rest. The scan time for the part of the $Scan_{stress}$ to simulate the $Stress_{shine\text{-}through}$ scan, was based on the percentage of activity left over from the stress scan, A_{left_over}, after 3-h delay as measured in patients, and as described in Eq. 3. The scan times for the rest scan were calculated using the mean count ratio in patients as calculated using Eq. 1 for the different RSARs to simulate the use of the different RSARs, as described in Eq. 4.

$$Scantime_{stress_{shinethrough}} = T_{stress} \cdot A_{left\_over} \quad (3)$$

$$Scantime_{rest} = Scantime_{stress_{shinethrough}} \cdot CountRatio \quad (4)$$

Next, we reconstructed all images and automatically calculated the SDS and iTPD for all scans using Quantitative Perfusion SPECT software (QPS, v2009, Cedars-Senai

Medical Center). We derived the lowest RSAR which resulted in the same defect interpretation based on iTPD or SDS as compared to using a RSAR of 4.0. Scans with a SDS deviating >2 or iTPD ≥7% in comparison with the SRAR of 4.0 reference scan were considered to represent a true change in defects [18–20].

Deriving the minimal stress–rest activity ratio

To determine the influence of different RSARs on the visibility of ischemia in patients, we simulated the use of different RSARs using the raw projection data of group A. First, we derived a rest acquisition without any shine-through, $Acq_{no\_shine\_through}$, by:

$$Acq_{no\_shine\_through} = Acq_{rest} - Acq_{pre-rest} \quad (5)$$

Here, Acq_{rest} is the original rest projection data and $Acq_{pre-rest}$ the pre-rest projection data, as shown in Fig. 2. To obtain six additional simulated rest studies with varying RSARs for each patient, the number of measured counts acquired in the projection data from the scan without shine-through was reduced for each detector element by a factor K (see Eq. 2) using the following $RSAR_{sim}$: 1.0, 1.5, 2.0, 2.5, 3.0, 3.5. We than derived six simulated rest acquisitions for the varying RSARs using:

$$Acq_{sim-rest} = Acq_{no\_shine\_through} \cdot K + Acq_{pre-rest} \quad (6)$$

Next, we reconstructed the original acquisitions and the six additional simulated rest acquisitions. The occurrence of possible shine-through effects in the simulated rest scans was assessed by comparing the iTPD (≥7%) and SDS (>2) of the simulated with that of the reference RSAR. In addition, the short, vertical long and horizontal long slices of all six modified rest scans were displayed next to each other in one plane with the reference scan on the left side. Next, two experts visually assessed the images and marked the reconstructions possibly deviating from the reference scan. In case of disagreement, a third expert interpreted the scans with overread. All experts were masked to patient characteristics and RSARs and simulated scans were presented in random order. The minimal RSAR not resulting in true changes of defects in comparison to the reference RSAR of 4.0 in both phantom and patient results was chosen to be validated in the second part of this study.

Validating the minimal stress–rest activity ratio

The minimal RSAR was validated in 25 patients in group B. The rest scans created using the minimal RSAR of 2.0 were compared with those using the reference RSAR of 4.0. Possible differences between the minimal RSAR in comparison to the reference RSAR were assessed. Changes in SDS >2, iTPD ≥7% and ischemic defect interpretation by two experts in consensus were considered to represent a true change in defects [18–20]. In addition, we also assessed the change in diagnostic outcome using a SDS > 2 as threshold for ischemia.

Statistical analysis

Patient-specific parameters and characteristics were determined as mean ± standard deviation (sd) or percentages using R (v3.4.1, 2017). The number of scans with a deviating iTPD, SDS or visual outcome were compared between the different RSARs with the highest simulated RSAR of 3.5 using the McNemar test. The level of statistical significance was set to 0.05.

Results

The baseline characteristics of all 47 included patients are summarized in Table 1.

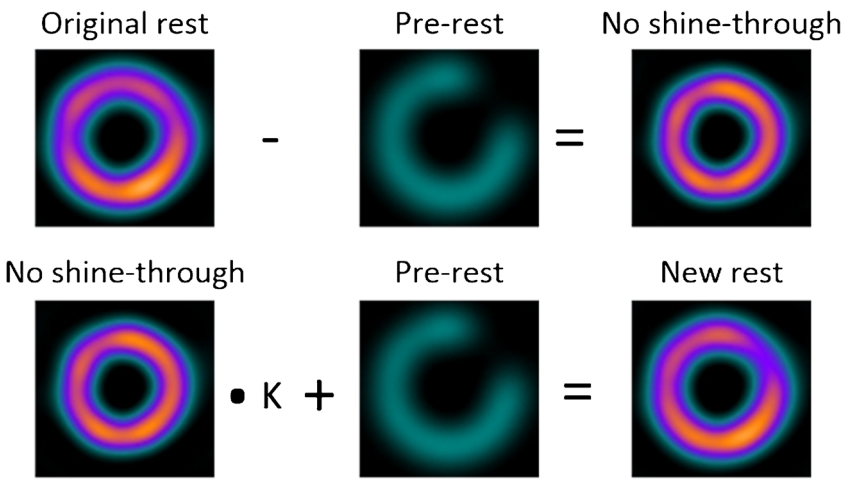

Fig. 2 Schematic overview of the method to simulate scans with different rest–stress activity ratio (RSAR) in group A. K is the conversion factor used to simulate the different RSARs

Table 1 Baseline characteristics and scan outcome of all 47 patients who underwent clinically indicated MPI CZT-SPECT. In group A we derived the minimal RSAR of 2 and consecutively validated this ratio in group B

Characteristic	Group A (N = 22)	Group B (N = 25)
Age (years)	61.5 ± 9.1	61.1 ± 9.8
Male gender	55	64
Body weight	90.6 ± 22	81.3 ± 10
Body mass index (BMI)	28.8 ± 5.1	27.4 ± 3.7
Current smoking	5	20
Hypertension	68	60
Diabetes	18	20
Dyslipidemia	45	52
Family history	68	56
Ejection fraction (%)	63 ± 10	61 ± 8
Normal MPI scan	50	52
Ischemic defect	45	32
Irreversible defect	5	28

Values are presented as mean ± SD or as percentages

Washout

The mean number of measured photon counts in the stress scans was 108 ± 33 kcts/min. This decreased to 27.2 ± 8.3 kcts in the pre-rest scans after 183 ± 29 min (range 131–229 min). The remaining activity in the pre-rest was 26% of the original activity. This decrease can be explained for 32% by radioactive decay whereas 68% was due to biological washout. None of the patients had significant gastro-intestinal activity which may have influenced these results. The mean number of measured counts in the rest scans was 520 ± 155 kcts/min. The time between the pre-rest and rest scan was 60 ± 7 min. The mean photon count ratio between the remaining activity from the stress injection and the rest injection when using a RSAR of 4.0 was 1:18.5 ± 3.1 and decreased to 1:4.0 ± 0.8 for a RSAR of 1.0, as shown in Table 2.

Phantom study

Lower SDS and, hence, underestimation of the defect reversibly was observed for lower RSARs in the phantom study, as shown in Fig. 3a. Whereas the SDS deviated ≤2 for RSARs of 2.0 or higher, it resulted in true changes in defects when lowering to RSAR of 1.5 or 1.0. The iTPD varied between the different RSAR scans but did not deviate ≥7% from the RSAR 4.0, as shown in Fig. 3b.

Deriving the minimal stress–rest activity ratio

Comparing the simulated RSARs with the reference RSAR in patients revealed similar results as the phantom study.

Table 2 Count ratios of the stress and rest injections in 22 patients for the various simulated stress–rest activity ratios (RSAR) when incorporating a mean delay of 3 h between stress and rest injections and accounting for biological washout and radioactive decay

RSAR	Count density ratio	
	Mean ± SD	min-max
4.0	18.5 ± 3.1	11.3 - 24.6
3.5	16.1 ± 2.8	9.8 - 21.4
3.0	13.7 ± 2.4	8.3 - 18.2
2.5	11.2 ± 2.0	6.8 - 15.0
2.0	8.8 ± 1.6	5.2 - 11.8
1.5	6.4 ± 1.2	3.7 - 8.6
1.0	4.0 ± 0.8	2.2 - 5.5

SDS differences >2 were not found using RSAR 3.0 and were found in one patient each using RSAR 3.5, 2.5 and 2.0, as shown in Fig. 4. The number of scans with a SDS > 2 increased to 3 (14%) and 5 (23%) patients when using a RSAR of 1.5 or 1.0, respectively ($p > 0.13$). No iTPD difference > 7 was observed when comparing the iTPD of the different simulated RSAR with the reference RSAR. The number of scans visually interpreted as having a possibly altered scan outcome seemed to increase for the lower RSAR ratios but this was not significant ($p > 0.22$).

Based on the results of the phantom and first part of the patient study, we concluded that a RSAR of 2.0 did not result in different outcomes when accounting for the observed reproducibility variation in higher RSARs. A RSAR of 2.0 was therefore validated in clinical practice.

Validating the minimal stress–rest activity ratio

When comparing the scans with a RSAR of 2.0 and 4.0 in 25 patients, the SDS differed in one patient by >2, as shown in Fig. 5a. However, this patient already had a SDS of 30 using the reference scan and this became 11 using RSAR 2.0, still indicating severe ischemia. The iTPD did not differ ≥7% between both RSARs in any patients, as shown in Fig. 5b. The same tendency was observed for the visual interpretation. In eight of the 25 patient ischemia was detected using either RSAR 2.0 or the reference 4.0. Two scans were interpreted as ischemic using RSAR 2.0 whereas these were interpreted as non-ischemic using the reference RSAR. Yet in another two patients ischemia was detected using the reference RSAR whereas these were interpreted as non-ischemic using RSAR 2. In all these four patients, defect changes were observed in the interior wall. Looking at irreversible defects, six scans where identified as such using RSAR 2.0 whereas this was only detected in four of these patients using RSAR of 4.0. When looking at the number of patients with ischemia based on a SDS > 2, eight patients were identified as ischemic using

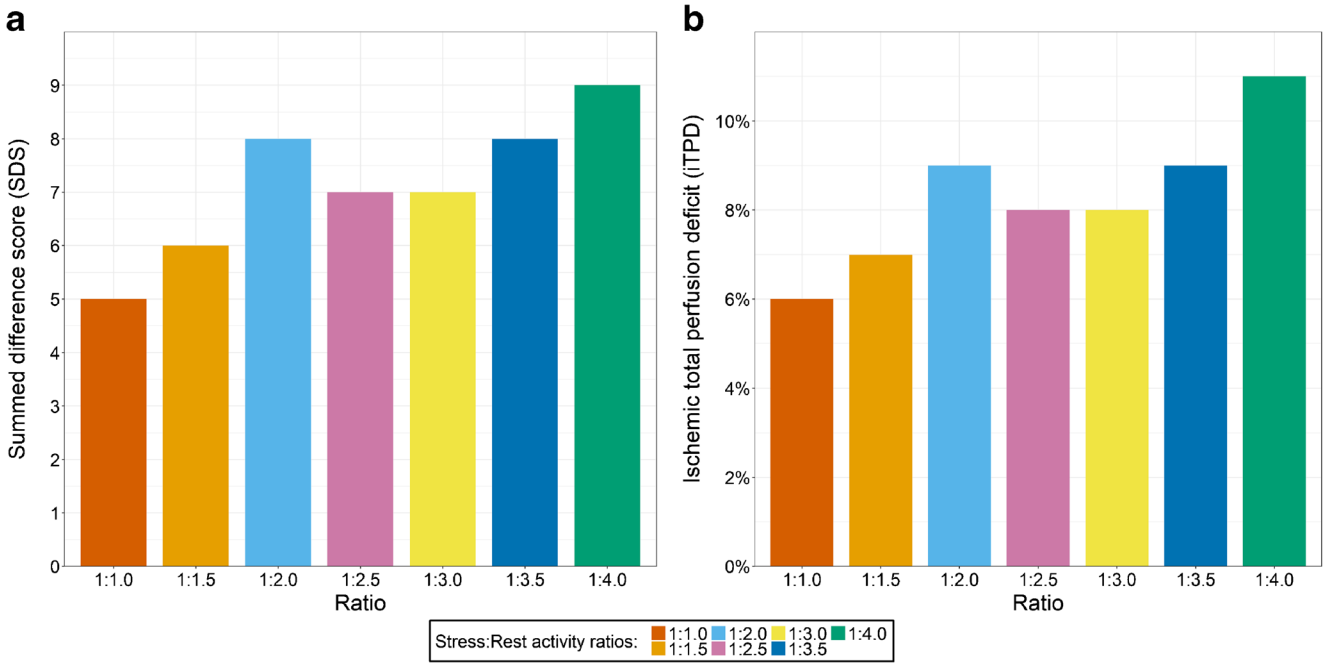

Fig. 3 Results of the phantom study showing (**a**) the summed difference score (SDS) (**a**) and the ischemic total perfusion deficit (iTPD) (**b**) for four different stress–rest activity ratios (RSAR) for four different simulated defect severities. A SDS difference > 2 and iTPD difference of ≥7% in comparison to the reference ratio of 1:4 was considered to result in a true change of defects

the RSAR 2.0 and the diagnosis changed in one patient to normal using RSAR 4.0 (Fig. 6).

Discussion

In this study, we have demonstrated that a rest–stress activity ratio (RSAR) of 2.0 in SPECT MPI with a 3-h delay between the stress and rest injection is sufficient to maintain diagnostic value in terms of summed difference score, total perfusion deficits and visual outcomes. We also demonstrated that a 3-h delay between stress and rest injection majorly increases the stress–rest photon count ratio to 1:8.8 for a RSAR of 2.0 and, hence, diminishes shine-through effects due to the high biological washout. Using a RSAR lower than 2.0 led to a substantially lower diagnostic value and is therefore not recommended.

Although a RSAR of 3 is recommended in international guidelines, evidence is scarce. Only a limited number of studies have studied the effect of using different RSARs [11, 21].

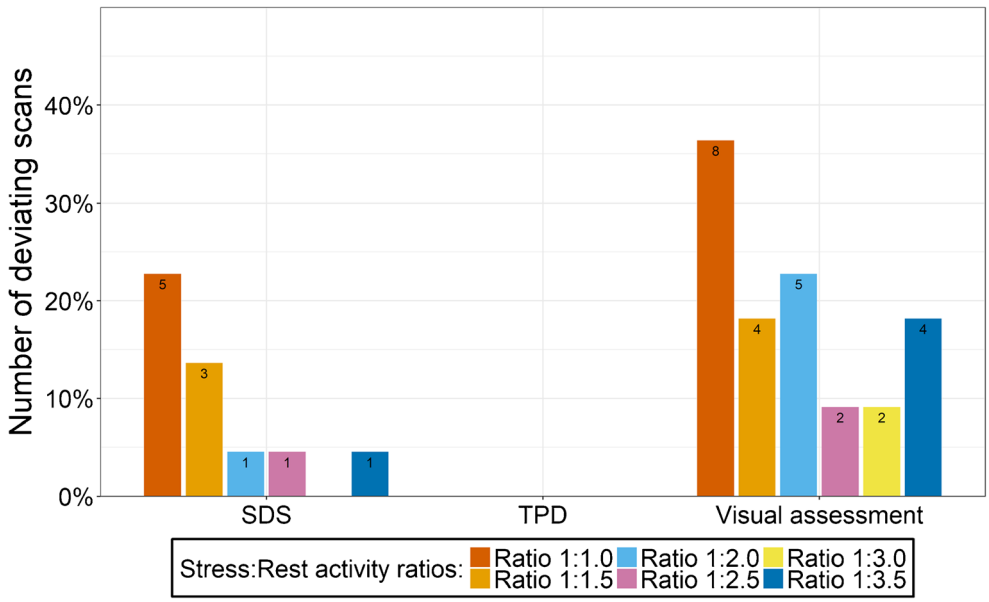

Fig. 4 Bar chart showing the percentage of scans for the various stress–rest activity ratios (RSAR) in which the differences in SDS, iTPD or visual interpretation were considered to influence the diagnostic outcomes in comparison to the reference scan. Although the number of deviating scans seemed to increase for lower RSAR, this difference was not significant ($p > 0.22$). Moreover, the iTPD did not differ ≥7% in any of the scans. The *numbers in the bars* indicate the number of patients

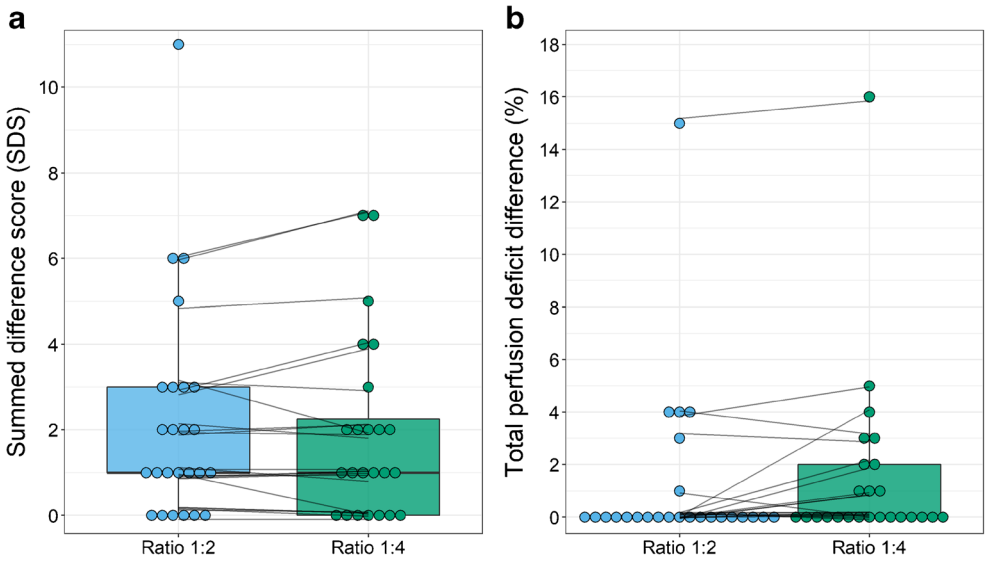

Fig. 5 Box plot showing the summed difference score (SDS) (**a**) and in total ischemic perfusion deficit (iTPD) (**b**) using the minimal and reference ratio. Each *dot* represents a patient and the lines connect the two measurements for the different ratios. The outlier in **A** represent the patient in which the SDS increased from 11 to 30 (point not shown) when using the minimal and reference ratios, respectively

Nkoulou et al. introduced a subtraction algorithm to correct for possible shine-through effects allowing to use a RSAR of 1 [21]. Although they reported promising results, dedicated software is needed for these subtractions which makes it hard to implement for other institutions. DePuey et al. performed a patient and complementary phantom study and concluded that a photon count ratio of 5.8 between stress and rest would be sufficient, corresponding to a RSAR of 4.0 without any time delays [11]. However, they excluded the effect of radioactive decay during the waiting time between stress and rest and did not incorporate the biological washout of the stress activity during this delay. Hence, in clinical practice a higher count density ratio would be achieved with a lower RSAR. For example, when accounting for the 74 ± 5% washout after 3 h, we obtained their recommended count density ratio of 5.8 in almost all of our patients when using a RSAR 2, as

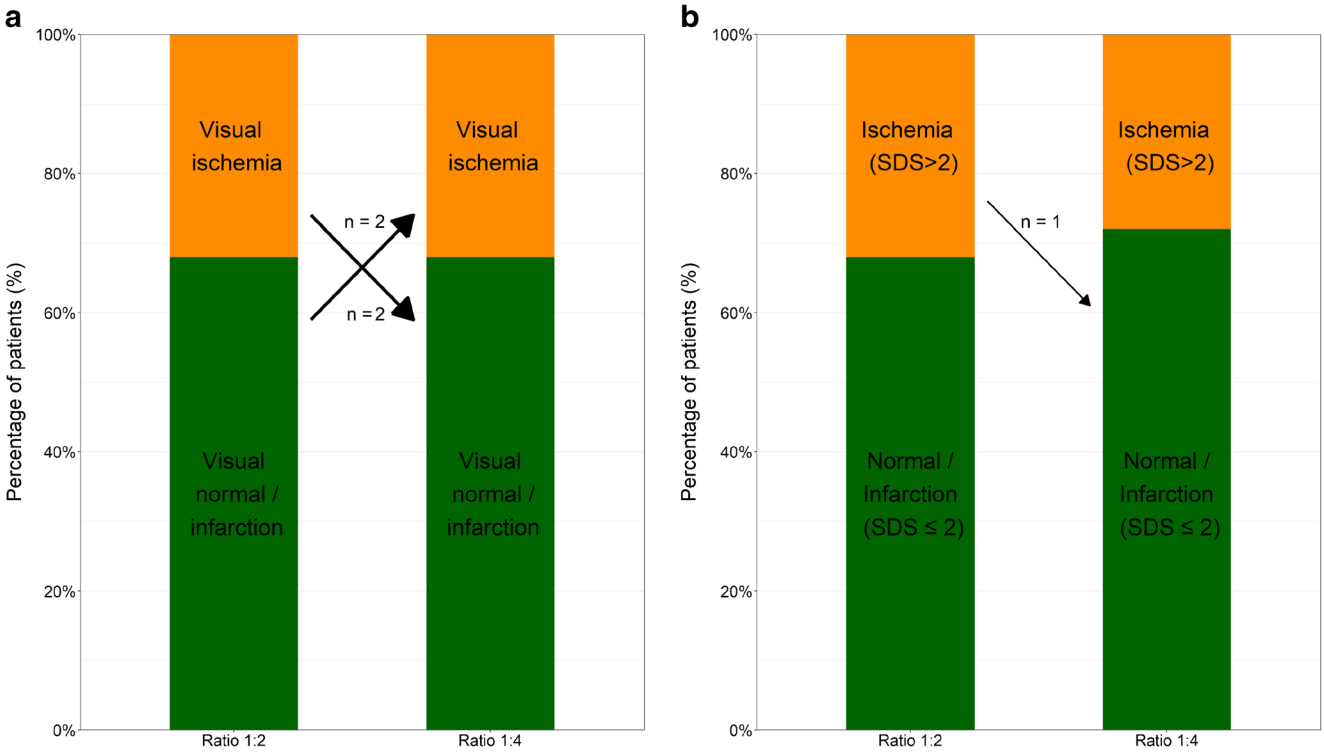

Fig. 6 *Bar charts* showing the percentage of patients with a normal or ischemic defect interpretation (**a**) as assessed by two experts and based on a SDS > 2 (**b**) using the minimal and reference ratio. In 21 of the 25 patients the interpretation was identical using visual interpretation whereas it was identical in 24 out of 25 patients using the SDS, as indicated with the *arrows*

shown in Table 2. Our phantom results are also in high agreement with those of DePuey et al., showing minimal shine-through effects using a RSAR of 2.0 while accounting for decay and washout. The European guidelines currently refer to the study by Heo et al. for the use of a RSAR of minimal 3. However, the main aim of their study was to determine the diagnostic accuracy of SPECT MPI. Nevertheless, the used RSAR of 3 has since then been set as the standard minimum RSAR to be used, although a minimal RSAR has never been established [9, 10, 12].

Several limitations of this study should be recognized. First, we included all consecutive patients who were referred for rest imaging instead of solely ischemic patients. Underestimation of defect severity due to shine-through effects will only occur in ischemic patients during rest imaging thereby limiting our effective cohort [11]. We were unable to solely include ischemic patients as scan outcomes were not available at the time of inclusion due to the absence of the rest study. However, the complementary phantom study, validation part of this study and agreement with previous literature provides sufficient evidence that a RSAR of 2.0 with a 3-h delay prevents shine-through effects.

Second, we determined the washout effects by calculating the counts in the whole field of view instead of in a region of interest encapsulating the myocardium. However, the pinhole design of the used CZT-based SPECT camera establishes a small FOV that is already focused on the myocardium, minimizing the influence of surrounding tissue. In addition, none of the patients had significant gastro-intestinal activity which might have influenced the washout rate. The variance in biological washout rate was also relatively small (SD = 7%), indicating a low reproducibility error.

Third, attenuation correction was not applied in this study to prevent inclusion of additional reproducibility errors [14]. When attenuation correction is applied on the same acquired data, this will result in identical images. However, in case of a different attenuation profile, for example, when a breast is in a different position after repositioning the patient for a second scan, this inter-scan variability could influence the diagnostic outcome. Thereby, the contraction of the left ventricle was not assessed using gated images as they were not acquired during the pre-rest and additional rest examinations in this study. This might explain the four patients of which two scans were visually interpreted as having ischemia using RSAR 2 and normal using RSAR 4 and two scans in which the opposite was observed. Especially when considering that in all four scans ischemia was observed in the inferior wall which is the most susceptible for attenuation artefacts.

Finally, although differences were observed in SDS and visual outcomes between the reference and lower RSAR scans, RSARs≥2 were still considered to achieve the same diagnostic value as the reference scan. Yet RSARs 1.0 and 1.5 seemed to be inferior to RSARs ≥2 based on the higher differences in SDS in both the patient and phantom study and the changes in visual defect interpretation which seemed to exceed the encountered reproducibility errors. This assumption was confirmed in the validation part of the study where we showed that lowering the RSAR to 2.0 only affected the diagnosis within the margin of reproducibility and inter-observer variation. The SDS changes between RSAR 2.0 and 4.0 were all within previously reported reproducibility errors for the SDS [20]. Moreover, the different visual interpretation of four patients can be explained by inter-observer variabilities which are known to be around 50–80% [22, 23].

Clinical consequences

This manuscript provides new insights and has several clinical consequences. First, the derived minimal RSAR of 2.0 when using a 3-h delay is in contrast with international guidelines suggesting RSARs of 3. More specific, the ASNC guidelines recommend the use of a 2-h delay but also suggest that a shorter delay can be compensated by increasing the activity of the rest injection to compensate for the radioactive decay [9, 10]. However, this approach heavily underestimates the influence of the biological tracer washout which was 68% of the total washout after 3 h. Hence, we recommend to incorporate a 3-h delay between stress and rest to minimize radiation exposure and limit shine-through effects or to use a higher RSAR to compensate for both radioactive decay and biological tracer washout.

Secondly, reducing the rest activity to two instead of three times the stress activity will result in a radiation exposure reduction of 25%. This implies that when a standard average activity of 370 MBq is used for stress injection, the rest activity will be reduced from 1110 to 740 MBq. The total radiation dose will thereby decrease from 9.1 to 6.8 mSv.

Finally, although the study was performed on a CZT-based SPECT camera using tetrofosmin, our results are assumed to hold on conventional SPECT cameras when using Technetium-99 m based tracers. Although the camera design and detectors of CZT-based SPECT are different from conventional cameras, the shine-through phenomena and hence the recommended RSAR is presumed to be independent of the camera. Moreover, choice of tracer is also not expected to influence possible shine-through effects as the extraction fraction of sestamibi in rest is similar to that of tetrofosmin and both radiopharmaceuticals have minimal redistribution [24].

Conclusion

The minimal stress–rest activity ratio needed to prevent relevant occurrence of shine-through effects and, hence, different diagnostic outcomes using a one-day MPI SPECT protocol seems 1:2 when using a 3-h delay between the stress and rest

activity injections. This ratio is significantly lower than generally believed.

Compliance with ethical standards

All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Disclosures None of the authors have anything to disclose.

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