Design of heart defects for in vitro perfusion reduction testing

I Chrysanthou-Baustert¹, Y Parpottas¹,², O Demetriadou³, D Kaolis⁴,⁵, S Christofides⁶,⁷, Ch Yiannakkaras⁴ and M Wasilewska-Radwanska⁶

¹ Frederick Research Center, Nicosia, Cyprus
² General Department (Physics-Math), Frederick University, Nicosia, Cyprus
³ Nuclear Medicine Department, Limassol General Hospital, Limassol, Cyprus
⁴ Medical Physics Department, Nicosia General Hospital, Nicosia, Cyprus
⁵ Biomedical Research Foundation, Nicosia, Cyprus
⁶ AGH University of Science and Technology, Krakow, Poland

E-mail: isabelle.chrysanthou@gmail.com

Abstract. Solid heart defects were designed to simulate regions of various contrast agent concentration by simply being immersed in a container with a radiopharmaceutical solution. The design was tested and verified by Monte Carlo simulation. Preliminary experimental results were taken on a gamma camera. The lower radiopharmaceutical concentrations were obtained by removing a certain volume of material, isotropically, from a solid cube of perspex material. The resolution of the imaging modality does not resolve the structure of the cube and the carved cube appears as a region of lower radiopharmaceutical concentration. It is also verified with Monte Carlo simulations, obtaining profiles across low radiopharmaceutical concentration areas that vary by less than 3%. The preliminary imaging results confirmed that the gamma camera could not resolve the internal structure of the carved cube and that partial volume effect resulted in image intensity reduction.

1. Introduction
Quantitative analysis of extent and perfusion reduction of heart problems in nuclear cardiology is calculated by processing the raw SPECT images with commercial software [1-3]. The verification of these results can only be made by comparing the results to a priori know situations usually with the use of a phantom. While extend is easy to be simulated in a phantom, perfusion reduction can only be tested by introducing a small container filled with a lower radiopharmaceutical concentration within a higher radiopharmaceutical concentration. We have designed solid defects, which when immersed in a solution of high radiopharmaceutical concentration, produce regions of known lower radiopharmaceutical concentration. In this paper, the design of the solid heart defects, together with its validation using Monte Carlo simulations, and preliminary imaging results with a clinical scanner (γ-camera) are presented.

2. Method
The new defect design consists of a solid cube from which a certain volume has been removed in an isotropic way such that radiopharmaceuticals can penetrate the perforated structure but the resolution of the imaging modality cannot resolve the structure of the cube. As a result of the partial volume effect, a predictable lower radiopharmaceutical concentration appears in the image.
2.1. Defects using Monte Carlo simulations

Monte Carlo simulations with the SIMIND code were performed to investigate the validity of the heart defect design. The following settings were used: LEHR collimator, 140 keV photons with an energy resolution of 10%, a 20% energy window centered around 140 keV, a 64x64 matrix, a pixel size of 0.63 cm, and one projection at 0° was recorded. The simulation setup is described below.

First, a rectangular source of 6x4x2 cm size was simulated with a cubic insert of 10 mm sides. The insert was programmed to contain various lower concentrations of radiopharmaceutical (32%, 50% and 66.5% of the surrounding source). This reduction simulated a defect with reduced perfusion.

Second, a similar setup was simulated with a solid cube with a certain percentage of its material removed was placed at the position of the cubic insert. The material was removed in such a way that the clinical scanner could not resolve its structure and, thus, the simulated partial volume effect, where the overall radiopharmaceutical concentration seen by the clinical scanner, was reduced by the amount of the solid volume remaining. Various radiopharmaceutical concentrations were simulated by increasing or reducing the volume of the removed material for the solid cube. In each cube, 16 small cylinders were removed with diameter 1.6, 2 and 2.3 mm resulting in a percentage of 32%, 50% and 66.5% removed volume, respectively.

2.2. Manufactured defects

Small volumes of perspex were cut and a predefined volume of material was removed in such a way that water can penetrate through the remaining structure and that the gamma camera cannot resolve its fine structure. As a result, the gamma camera detects a lower radiopharmaceutical concentration.

Perspex cubes of 10 mm side were cut on an 80 W CO₂ laser cutter. 52% of its volume was removed by cutting out 23 small cylinders of 1.7 mm diameter. Figure 1 shows a manufactured defect of 10x10x10 mm with 52% of material removed.

We used coloured water to assess the ability of the holes to fill up with water without any remaining air bubbles when immersed. The capillary effect helped to fill the holes without any air bubbles.

For the in vitro experiments, two similar cubes were carefully immersed into a water cylindrical test flask container, of 1.5 cm diameter and 8 cm length, to which radiopharmaceutical was added. The vial was tightly closed and inserted into the Nuclear Associates PET/SPECT Phantom Source Tank (Fluke Biomedical). SPECT imaging was performed on a GE advantage scanner.

![Figure 1. Manufactured perspex defect of 10x10x10 mm with 52% of material removed.](image)

3. Results

3.1. Monte Carlo simulations

The results of the Monte Carlo simulations were assessed visually by drawing profiles across the regions of the two types of simulated defects (a vial with 50% radiopharmaceutical, a cube with 50% of its volume removed as small cylinders). As figures 2 and 3 show, there is no visual difference between the images and, further, there is perfect agreement between the two different defect types with deviations in profiles lower than 3%. The internal structure of the cubes could not be resolved by the gamma camera.

On the 0° projections profiles, a reduction in counts is observed in the region of the cubes with removed volumes. The image intensity dropped by approximately 13.5%. The internal structure of the
cubes could not be resolved by the gamma camera. However, on the 90 ° projections profiles, no signal-drop could be observed in both cases because of the vial geometry.

![Figure 2](image1.png)  
**Figure 2.** 0° projection of a source, with Monte Carlo simulations, containing (a) a vial with 50% radiopharmaceutical, (b) a cube with 50% of its volume removed as small cylinders, (c) profiles across the images (white lines); blue colour for the first case and red colour for the second case.

![Figure 3](image2.png)  
**Figure 3.** 90° projection of a source, with Monte Carlo simulations, containing (a) a vial with 50% radiopharmaceutical, (b) a cube with 50% of its volume removed as small cylinders, (c) profiles across the images (white lines); blue colour for the first case and red colour for the second case.

### 3.2. Manufactured defects

Figure 4 shows a screenshot of the results obtained from the structure (two similar cubes immersed in the container) described in section 2.2 using a gamma camera at 0° projection. In the region of the two cubes (top parts of figures 4a and 4b), fewer counts are observed. The count reduction in the region with the cubes is of the order of 14%.

![Figure 4](image3.png)  
**Figure 4.** Screenshots of the results obtained from the structure described in section 2.2 using a gamma camera at 0° projection: (a) black and white scale, (b) colour scale with ROIs (white circles). The two circles (ROIs) at the top part of figure 4b include the two cubes.
Conclusions
The results show that various predefined radiopharmaceutical concentrations can be created in one single container without the need of further dilutions. The experimental setup can be easily reproduced. This concept could potentially be used to design new generation of QA phantoms in assessing the accuracy of the image reconstruction algorithms, in the quantification of radiopharmaceuticals and in the assessment of the limitation of quantitative nuclear medicine.

Acknowledgments
This work is funded by the Cyprus Research Promotion Foundation and the European Regional Development Fund through the project YTEIA/ΔYTEIA/0308/11: Optimising Diagnostic Value in SPECT Myocardial Perfusion Imaging.

References
[1] Ficaro E P, Lee B C, Kritzman J N and Corbett J R 2007 J. Nucl. Cardiol. 14(4) 455-465
[2] Germano G, Kavanagh P B, Slomka P J, Van Kriekinge S D, Pollard G and Berman D S 2007 J. Nucl. Cardiol. 14(4) 433-454
[3] Garcia E V, Faber T L, Cooke C D, Folks R D, Chen J and Santana C 2007 J. Nucl. Cardiol. 14(4) 420-432