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To cite this article: I Chrysanthou-Baustert *et al* 2011 *J. Phys.: Conf. Ser.* **317** 012018

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Monte Carlo simulations to assess differentiation between defects in cardiac SPECT

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Abstract. Differentiating between various types of lesions in nuclear cardiology is a challenge. This work assesses the level of differentiation achievable between various low contrast lesions, as encountered in nuclear cardiology. The parameters investigated are defect extend, defect thickness and perfusion reduction of the defect. The images have been obtained through Monte Carlo Simulations with the program SIMIND. Results show that acceptable size resolution is obtained for defects with an extend over 25x25mm. When thickness and perfusion reduction are both unknown, the imaging results are confounding. In this work, thickness and perfusion reduction cannot be differentiated. If one of the variables is known (thickness or perfusion reduction), imaging results can differentiate between the other unknown variable.

Introduction

The detection of a cardiac defect relies on resolving a low radiopharmaceutical concentration within a higher activity. Previous publications have assessed the limitations of resolving cardiac defect characteristics with simulations of a dynamic cardiac phantom [1-2] and with various commercially available post-processing softwares [3-4]. They report statistically relevant variations between the severity results computed by commercially available packages. The simulation studies further investigate the variation of minimum defect detection size with perfusion reduction and the inability to discriminate between different defect thicknesses and perfusion reductions in the heart. In this paper, Monte Carlo simulations are used to assess differentiation between low contrast defects, as encountered in nuclear cardiology. Three different parameters contributing to the resolution of lesions in the myocardium are analysed. The parameters investigated are defect extend, defect thickness and perfusion reduction of the defect (that is, the reduction of radiopharmaceutical concentration in the defect relative to the surrounding healthy heart).

Method

Monte Carlo simulations with the SIMIND [5] code were performed with the following settings: LEHR collimator, 140 keV photons with an energy resolution of 10%, a 20% energy window centred around 140 keV, a 64x64 matrix, a pixel size of 0.63 cm, 2 projections were recorded at 0° and 90°.

Thirty-three simulations were run with various defects immersed in a radiopharmaceutical concentration. The defect sizes are shown in **Table 1**. The defects were sequentially placed in a container of length 16 cm, width 6 cm and thickness 2 cm filled with ^{99m}Tc (100%). The shape was chosen to simulate the cardiac wall. The defect extend (30x30, 25x25, 20x20, 15x15 and 10x10 mm²) and thickness (5, 10, 15 mm) were varied. Further, the relative concentration of radiopharmaceutical (0%, 30%, 60%) was varied to simulate severe, moderate and mild perfusion reduction in the defects, respectively.

Table 1. The simulated defects sizes are indicated with a tick (✓). For each of the indicated defect size, the severe, moderate and mild perfusion reduction was simulated.

Extend (mm)	Thickness (mm)		
	5	10	15
10x10		✓	
15x15	✓	✓	✓
20x20	✓	✓	✓
25x25		✓	
30x30	✓	✓	✓

The analysis software was written in MATLAB (The MathWorks). The projections at 0° and 90° were analysed. Profiles along the x-axis, the y-axis and the z-axis were extracted from the projections. For quantitative analysis, the signal-drop, seen in the profiles due to the defects, was normalized to 100, and then inverted, which turned the signal-drop intensity into the signal intensity to increase. Then a gaussian function was fitted to characterize the amplitude and the FWHM of the signal intensity profile.

Results

All the defects could be observed by visual inspection. In figure 1, the 0° and 90° projections together with their profiles are shown for defect size of 25x25x10 mm and severe perfusion reduction (i.e. 0% radiopharmaceutical uptake in the defect), while in figure 2, are shown for defect size of 10x10x10 mm and severe perfusion reduction.

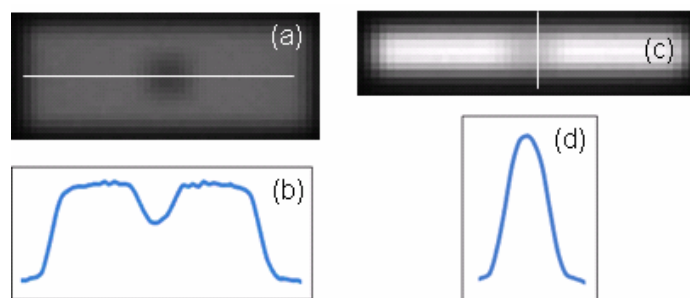


Figure 1. Simulation for defect size of 25x25x10 mm and severe perfusion reduction. (a) Image for 0° projection, and (b) the corresponding profile along the long axis (white line in a). (c) Image for 90° projection, and (d) the corresponding profile along the short axis (white line in c).

The quantitative analysis of the gaussian function, characterizing the inverted signal-drop intensity due to the defects, involves the computation of the FWHM and the amplitude. To visualise all the results, a scatter plot is shown in figure 3. The size is represented by the increasing square size and ranges from 1x1, 1.5x1.5, 2x2, 2.5x2.5 to 3x3 cm. The colour represents the perfusion reduction: green is mild, red is moderate and black is severe. The mark inside the square represents the thickness: ● is 5mm, + is 10mm and * is 15mm.

In a first step, the ability to resolve the extend of the defects is assessed. It can be observed from figure 3 (right part of the graph) that the defects with extend 30x30 mm are well resolved. The standard deviation of the fitted FWHM is of the order of 2.3%. The same can be argued for defects of extend 25x25 mm for which the standard deviation of the FWHM is of the order of 3.8%. For smaller defects, there is major overlap between all the defect extends. For defects with extend 20x20 mm² and below, the standard deviation of the FWHM is of the order of 10%.

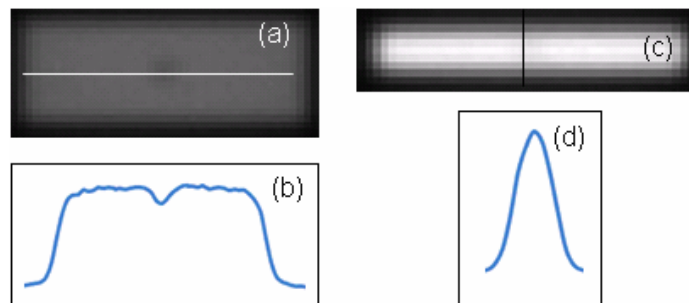


Figure 2. Simulation for defect size of 10x10x10 mm and 0% radiopharmaceutical uptake. (a) Image for 0° projection, and (b) the corresponding profile along the long axis (white line in a). (c) Image for 90° projection and (d) the corresponding profile along the short axis (black line in c).

In figure 3, it can be observed for the well resolved large-size defects (higher values of FWHM), that for each perfusion reduction (represented by the colour), there is differentiation between the thicknesses of the defects (represented by the internal mark), that is, thicker defects have larger amplitude in the figure. It can also be seen for the large-size defects that for each thickness, there is differentiation between the perfusion reductions of the defects, that is, more severed defects have larger amplitude. However, there is overlap between the thickness and the perfusion reduction of the defects. A thin defect with severe perfusion reduction produces the same signal-drop as a thick defect with moderate perfusion reduction. Only the two extreme cases (thick defect with severe perfusion reduction and thin defect with mild perfusion reduction) are well resolved.

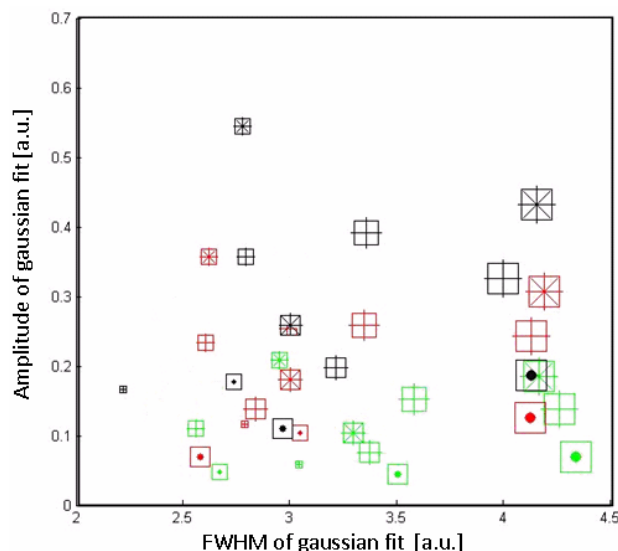


Figure 3. Scatter plot of the gaussian fit parameters, amplitude and FWHM, on the y and x-axis, respectively, for the three variables: extend of lesion, thickness of lesion and perfusion defect severity. The size is represented by the increasing square size and ranges from 1x1, 1.5x1.5, 2x2, 2.5x2.5 to 3x3 cm. The thickness is represented by the mark inside the square: ● is 0.5 cm, + is 1 cm and * is 1.5 cm thickness. The perfusion defect severity is shown by the colour: black is severe, red is moderate and green is mild defect.

For the small defect sizes, even though it is still obvious the relation between (a) same size and thickness of defects with different severity and (b) same severity and sizes of defects with different thicknesses, as for the large-size defects, there is no correlation among defect sizes; a major overlap is observed.

The profiles along the short axis (figure 1d and 2d) do not exhibit signal-drop intensity due to the defects geometry with respect to the short axis. To analyse these data, a gaussian was fitted to these profiles for various thicknesses and perfusion reduction of the defects. The FWHM variations are smaller than 2.5%. All 90° projection profiles for the 30x30 mm are shown in figure 4. For a given extend of the defects (i.e. 30x30 mm), the profile amplitudes vary as follows: lowest amplitude for the thick defect with severe perfusion reduction, and highest amplitude for the thinnest defect with the mildest perfusion reduction. Overlap also exists for defects with various thicknesses and perfusion reduction.

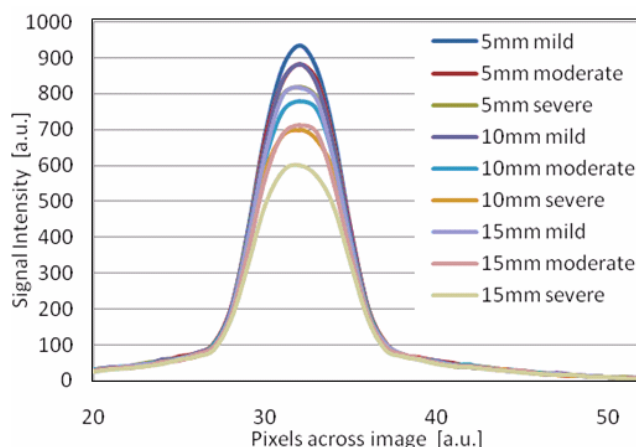


Figure 4. Profiles for 90° projections across the height of the simulated container with 30x30 mm inserted defects varying in perfusion reduction and thickness.

4. Conclusions

The difficulties in differentiating among different types of lesions in the heart with specialized post-processing software have been reported in previous publications. According to this investigation, the reason behind this problem is due to the basic limitations such as the low spatial resolution. Defect extend resolution becomes reliable above 25x25 mm. Even if the extend is well resolved for larger defect sizes, the thickness and perfusion reduction remains unresolved for any type of defect. It is therefore important to understand the clinical relevance of thickness and perfusion reduction in heart defects. In some clinical investigations, the physician might be interested to investigate only the perfusion reduction for a certain defect. Therefore, a constant defect thickness will be assumed and the report will focus on perfusion reduction of the defects.

The commercially available softwares are dealing with confounding imaging data (i.e. unresolved defect extends, defect thicknesses and perfusion reduction) and it is therefore not surprising that differences in various commercial implementations are reported.

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.

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