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Wall-less ^{18}F-doped gelatin phantoms for improved volume delineation and quantification in PET/CT

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INTRODUCTION

Positron emission tomography (PET) with ^{18}F-FDG is a valuable tool for staging, planning treatment, and evaluating the treatment response for many different types of tumours. The correct volume estimation is of utmost importance in these situations. To date, the most common types of phantoms used in volume quantification in PET utilize fillable, hollow spheres placed in a circular or elliptical cylinder made of polymethyl methacrylate (PMMA). To investigate the influence of the plastic walls, we developed a phantom without sphere walls for volume delineation and quantification in PET.

Figure 1. Aluminium mold with one of the ^{18}F-doped gelatin spheres.

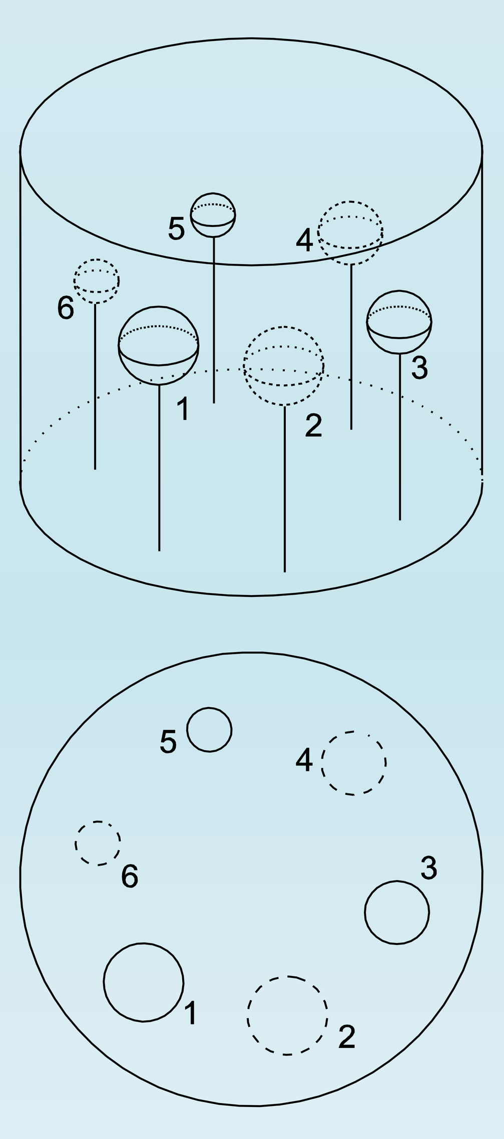

Figure 2. Illustration of the phantom including the placement of the hollow, plastic sphere inserts and the gelatin spheres. 1: Large plastic, 2: Large gelatin (ϕ: 27.9 mm), 3: Medium plastic, 4: Medium gelatin (ϕ: 22.5 mm), 5: Small plastic, 6: Small gelatin (ϕ: 15.6 mm).

MATERIALS AND METHODS

Three sizes of gelatin hotspots were moulded and placed in a Jaszczak phantom together with hollow plastic spheres of the same sizes (ϕ: 27.9 mm, ϕ: 22.5 mm and ϕ: 15.6 mm) containing the same activity concentration. ^{18}F PET measurements were made with zero background activity and with tumour-to-background ratios of 12.5, 10, 7.5, and 5. The background-corrected volume reproducing threshold, T_{vol}, was calculated for both the gelatin and the plastic spheres as described by Van Dalen *et al.* (2007) and Hofheinz *et al.* (2010). The threshold-based volume delineation method is based on the assumption that the activity in a point source in emission imaging can be described by a symmetric, three-dimensional Gaussian point spread function (PSF). To simulate the spatial resolution blur in the image, an ideal sphere is convolved with the PSF. The radial activity profile across a sphere is then described as:

$$P_z(z) = \begin{cases} \operatorname{erf}(Z) - \frac{2}{\sqrt{\pi}} Z e^{-Z^2} & (if\ z = 0) \\ \frac{1}{2}\operatorname{erf}(z+Z) - \operatorname{erf}(z-Z) - \frac{1}{2\sqrt{\pi}}\left[\frac{e^{-(z-Z)^2} - e^{-(z+Z)^2}}{z}\right] & (if\ z > 0) \end{cases}$$

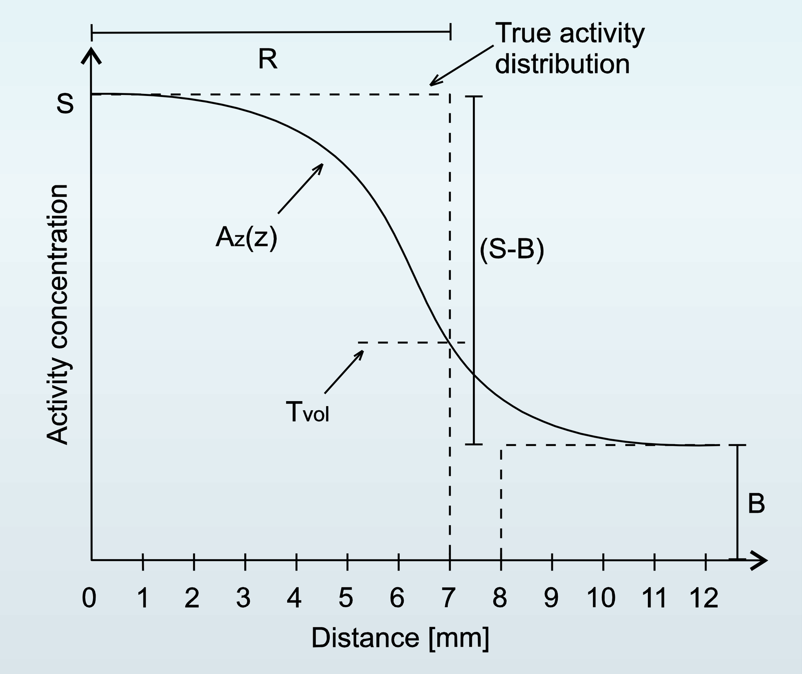

Figure 3. Illustration of the radial activity distribution in a sphere with a radius of 7 mm and a wall thickness of 1 mm. S is the signal intensity, B is the background intensity, $A_z(z)$ is the radial activity concentration profile of a sphere with signal S surrounded by a background B, and T_{vol} is the background-corrected relative threshold (in percent of (S-B)).

The value of the radial activity concentration profile at each coordinate z is given by:

$$A_z(z) = (S - B)P_z(z) + B$$

The background-corrected relative threshold is defined as the ratio of the background-corrected absolute threshold to the background-corrected signal at the centre of the sphere.

$$T_{vol} = \frac{A_z(Z) - B}{A_z(0) - B}$$

RESULTS

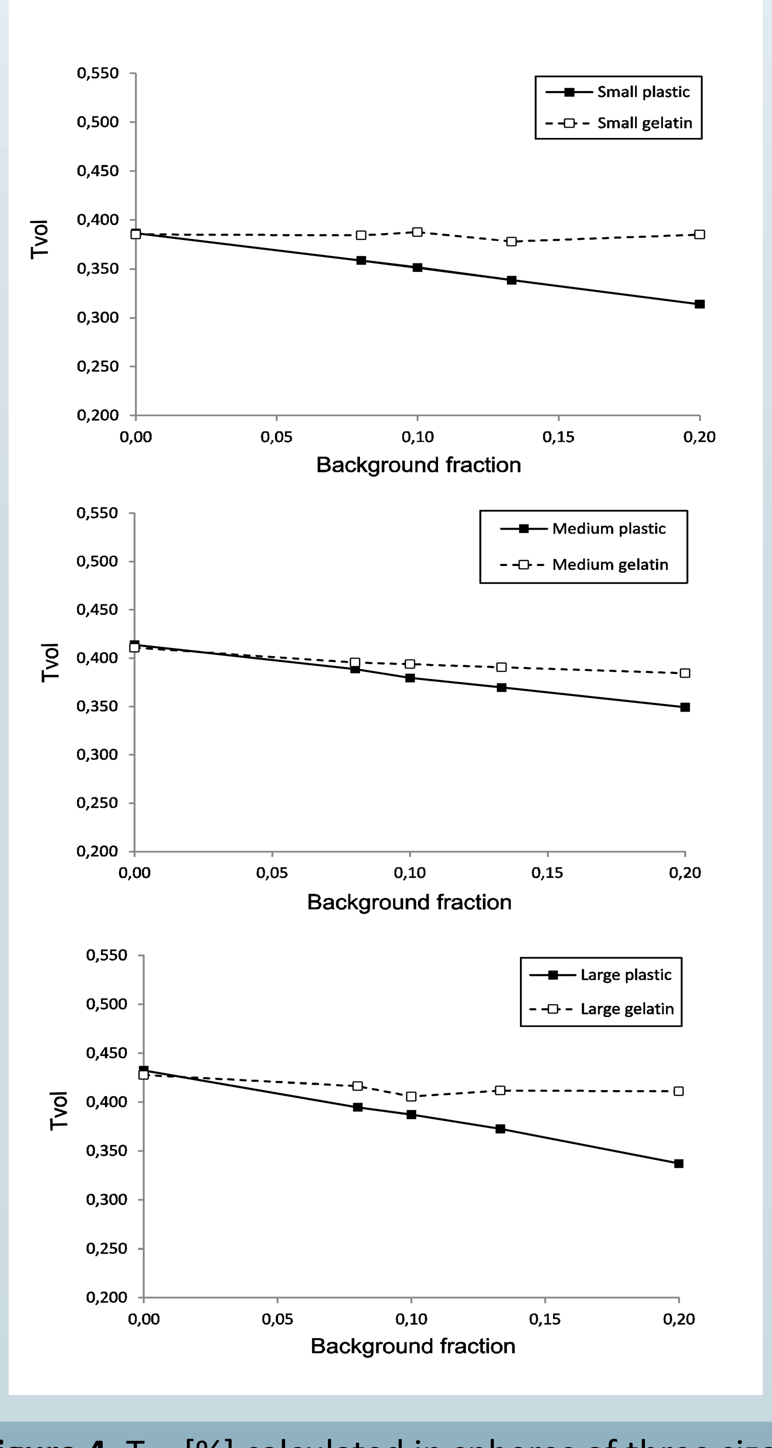

Figure 4. T_{vol} [%] calculated in spheres of three sizes (ϕ: 27.9 mm, 22.5 mm, and 15.6 mm) as a function of background fraction (BF) with and without non-active walls.

RESULTS

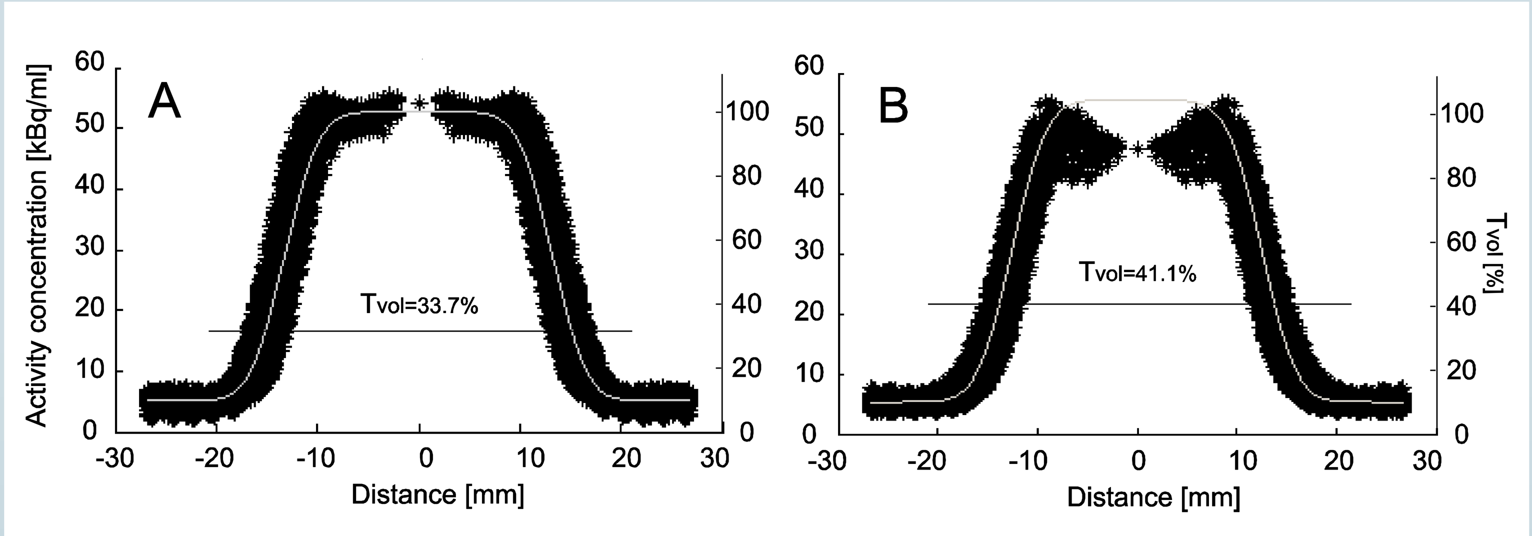

Figure 5. Measured radial activity concentration profile of the large plastic sphere (left) and the large gelatin sphere (right). An isotropic Gaussian PSF was fitted to the experimental data. The grey dotted line represents the background-corrected relative threshold, T_{vol} [%], which can be used to delineate the true sphere volume.

CONCLUSION

A phantom measurement approach based on radionuclide-doped gelatin spheres for volume delineation and activity quantification in PET was developed. For verification of the method, only spheres were moulded, but the phantom is easy to prepare and moulds could be made in any desirable shape depending on the application. Using the wall-less spheres, it was shown that the background-corrected threshold method is useful in defining tumour volume from PET images. It was also experimentally verified that the apparent background dependence, i.e., a decreasing T_{vol} with increasing background fraction, is not present for wall-less spheres. The opposite results were seen in plastic, hollow spheres in commercially-available phantoms. Thus, the threshold values estimated in phantom measurements, including spheres with non-active walls, should not be used for tumour delineation in patients as this would lead to erroneous volume estimations.

The work was conducted with funds from the Swedish Radiation Safety Authority

References:
Hofheinz F, Dittrich S, Potzsch C and Hoff J 2010 Effects of cold sphere walls in PET phantom measurements on the volume reproducing threshold *Phys Med Biol* **55** 1099-113
van Dalen J A, Hoffmann A L, Dicken V, Vogel W V, Wiering B, Ruers T J, Karssemeijer N and Oyen W J G 2007 A novel iterative method for lesion delineation and volumetric quantification with FDG PET *Nucl Med Commun* **28** 485-93