Quantitative SPECT: Opportunities and challenges

John Dickson, University College London Hospitals NHS Foundation Trust

Quantitative SPECT is a relatively new development in nuclear medicine imaging mostly driven by the rise in dosimetry following molecular radiotherapy. While from a superficial level the technique appears relatively straightforward, there are several challenges around optimisation that need to be realised before the technique can be successfully implemented. In this talk, existing and potential applications of quantitative SPECT will be presented before the process of SPECT quantification is broken down into its individual steps to understand how Quantitative SPECT can be optimised for clinical use.

SUV Fluctuations in "Identical" PET Reconstructions caused by Siemens Vision 600 Continuous Bed Motion Acquisition And Reconstruction Process

Clare McKeown, Mary Frances Dempsey, Sandy Small

Background.

Raw PET data cannot be stored on the Siemens Vision 600 PET-CT scanner long term due to the relatively large size of the data files and system storage constraints. Following the set-up of an offline raw data archive (Hermes Medical Systems), archived raw data was recovered and reconstructed using the original reconstruction parameters and quantitatively compared with the original reconstructions in order to validate the archive and recovery process. These reconstructions were expected to be identical; however, small discrepancies in voxel values were discovered. This led to further investigation into the Siemens Vision 600 reconstruction process.

Methods.

All PET data was acquired using Continuous Bed Motion (CMB) with a speed of 1.5mm/second and immediately reconstructed ("online reconstruction") using TrueX + TOF (4 iterations, 5 subsets), 440 matrix and a Gaussian post filter (FWHM 2mm). The raw data from 5 older patient studies reconstructions was recovered from archive and retrospectively reconstructed ("offline reconstruction") using the same reconstruction parameters. Quantitative ROI analysis of the reconstructed PET data (brain, liver, bladder and two lesions) of both activity concentrations and SUVs was performed both using Hermes Hybrid Viewer and GE Advantage Windows software.

Results.

Quantitative analysis demonstrated small SUV_{mean} differences in 2/25 ROIs and SUV_{max} differences in 4/25 ROIs (maximum absolute difference 0.01; maximum relative difference 0.56%). Although these differences are unlikely to be of clinical significance, any deviation between the reconstructions was a surprising result. Further comparisons of ROIs expressed as activity concentrations demonstrated differences in 24/25 mean and 22/25 maximum results.

DICOM header data was then interrogated. Discrepancies were discovered in the Scatter Fraction Factor (0054 1323) and Rescale Slope (0028 1053). Patient data, quantitative analysis and header data discrepancies were sent to Siemens engineers for further investigation.

Discussion.

Discussions with Siemens engineers [1] revealed that original "online" reconstructions in CBM mode reconstruct PET data in chunks that are equivalent to bed position sinograms in step/shoot mode; however, the list mode file used for later "offline" reconstructions is histogrammed into sinograms differently. This appears to have caused the small differences in the Scatter Fraction Factor and Rescale Slope. Furthermore, it was discovered that Rescale Slope can also vary between successive offline reconstructions: chunks of data are reconstructed in parallel to improve reconstruction speed and these may (or may not) be sequentially different each time.

Conclusion.

The use of CBM on the Siemens Vision 600 PET-CT system can cause small discrepancies in reconstructions performed using identical parameters, particularly when compared with the original "online" reconstruction. These differences are unlikely to be of clinical significance but may require consideration when undertaking quantitative assessments of the effects of altering reconstruction parameters.

Key references.

[1] Helen Smith, Siemens Healthineers, personal correspondence, October – December 2022

Phantom Validation of SPECT-CT Quantification with Varying Tc-99m Uptake

Christine Turner [1, 2], Catherine Humphreys[1], Cate Gascoigne[1].
[1]Swansea Bay University Health Board, [2]Swansea University.

Background. Absolute quantification of radiotracer distribution is a well-established technique in positron emission tomography (PET) and is becoming widely available in modern commercial single photon emission computed tomography-computed tomography (SPECT-CT) systems [1]. For some applications of quantification in SPECT-CT, such as dosimetry, accuracy is of high importance. Due to the partial volume effect, quantification accuracy decreases for objects smaller than three times the spatial resolution of the camera [2]. The aim of this phantom study is to validate the accuracy of SPECT-CT absolute quantification in relation to background to sphere activity concentration ratio, which is representative of tracer uptake in a lesion, and to investigate if accuracy can be improved for small volumes using empiric partial volume correction [3].

Methods. A GE 870DR NaI gamma camera was used to acquire SPECT-CT acquisitions of a NEMA Body PET-CT phantom containing 5 spheres (diameters 10 mm to 28 mm) filled with ^{99m}Tc. The background activity concentration was ~20 kBq/ml and the sphere to background concentration ratio was varied from 8:1 to 18:1. Two acquisition protocols were used for each concentration ratio- an idealised protocol and a clinically representative protocol. The initial calibration, acquisition reconstruction and quantification were performed using vendor neutral software. Ordered subset expectation maximisation (OSEM) reconstruction was used, with number of iterations, subsets, and post reconstruction filtering investigated to develop an optimised reconstruction method for quantification. These reconstruction parameters were used for all further processing with scatter correction, resolution recovery, and CT-based attenuation correction. Recovery coefficients (RC) were calculated for each sphere from the maximum and mean voxel values [4], giving RC_{max} and RC_{mean}, and a mean background RC was calculated, RC_{bg}. These values were used to assess quantification accuracy across the sphere sizes and concentration ratios. An anthropomorphic torso phantom was modified in house to contain spheres in the liver and around the spine of size and uptake representative of clinical hot lesions. This phantom was imaged as above and the recovery coefficients calculated. A recovery curve from NEMA Body phantom data was used to apply an empiric partial volume correction to sphere sizes <22 mm in all acquisitions for both phantom studies [3].

Results. The optimised OSEM reconstruction parameters were found to be 16 iterations, 6 subsets and a 6mm Gaussian post-filter. Using this reconstruction, the RC_{bg} of all regions in both phantoms was within 5% of the known value. The RC_{mean} of NEMA phantom spheres of diameter ≥22 mm was accurate to 10% for all concentration ratios. The RC_{max} and RC_{mean} showed a maximum standard deviation of 8% and 4% respectively for each sphere size across all measured activity concentrations. The activities of the larger spheres (>22 mm) in the liver insert of the torso phantom were measured within 5% of the known value. The partial volume correction improved accuracy in spheres for all concentration ratios for the NEMA phantom, and significantly improved accuracy for small spheres (<18 mm diameter) around the spine insert of the torso phantom.

Conclusion. The quantification accuracy for large sphere sizes both in the NEMA phantom and the modified anthropomorphic torso phantom was found to be within 10%, which is considered comparable to PET [4]. Low deviation in recovery coefficients across a range activity concentration ratios indicates the viability of an empiric partial volume correction in practice, and this was supported by the significant improvements seen in the accuracy of quantification in small volumes using a partial volume correction in the phantom studies.

Key references.

1. Bailey, D. L., & Willowson, K. P. (2013). An evidence-based review of quantitative SPECT imaging and potential clinical applications. *J. Nucl. Med., 54*(1), 83–89.
2. Lee, W. W., & K-SPECT Group. (2019). Clinical applications of technetium-99m quantitative SPECT/CT. *Nucl. Med. Mol. Imaging (2010), 53*(3), 172–181.
3. Dewaraja, Y. K. et al. (2012). MIRD pamphlet no. 23: Quantitative SPECT for patient- specific 3-dimensional dosimetry in internal radionuclide therapy. *J. Nucl. Med.,53*(8), 1310–1325.
4. Boellaard, R. et al. (2015). FDG PET/CT: EANM procedure guidelines for tumour imaging: Version 2.0. Eur. *J.Nucl. Med. Mol. Imaging, 42*(2), 328–354.

The establishment, validation and investigation of the potential applications of quantitative SPECT CT within ^{177}Lu-DOTATE in therapy monitoring

Alisia Maldon-Stanley, Royal Free Hospital and Kings College London

Background:

The aim of this project was to undergo the technical setup and experimental validation of SPECT CT quantification software xSPECT Quant, establishing optimal quantification of NETs for clinical evaluation in ^{177}Lu-DOTATATE therapy monitoring at the Royal Free Hospital. The aims are:

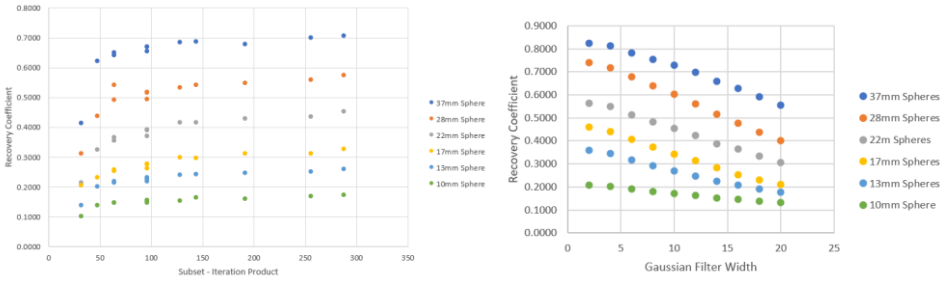
- Undertake calibration procedures in order to implement the use of xSPECT Quant at the Royal Free Hospital
- Optimise reconstruction parameters through a body of work using the NEMA IEC body phantom

Methods:

The body of work was carried out on a Siemens Intevo Bold gamma camera with Medium Energy Low Penetration (MELP) collimators, equipped with the quantitative SPECT CT reconstruction software xSPECT Quant. Both a cylindrical uniformity phantom and a NEMA IEC body phantom were used in the technical setup and experimental validation of this software. The cylindrical uniformity phantom was filled with a concentration of 50.29kBq/ml, and circular ROI's were drawn to obtain a value of 50.66kBq/ml, which only has a percentage difference of 0.74% from that which was expected and proved the possibility of quantification on the system. A NEMA IEC body phantom was filled with a ratio activity of approximately 10:1. The six 'hot' spheres contained an activity concentration of 170kBq/ml, whilst the 'colder' background region was filled with an activity of 17kBq/ml and imaged, with an acquisition using 256x256 matrix size and a non-circular step and shoot movement, as per the xSPECT Quant instruction manual. The reconstruction parameters were varied give the best recovery coefficient:

- Iterations (i) and subsets (s) were varied as follows: 8i 4s , 8i 8s, 8i 12s, 12i 4s, 12i 8s, 12i 12s, 16i 4s, 16i 8s, 16i 12s, 24i 4s, 24i 8s, 24i 12s
- Gaussian filter was varied to the following widths (after determination of the best subset-iteration product): 2mm, 4mm, 6mm, 8mm, 10mm, 12mm, 14mm, 16mm, 18mm, 20mm

Results:



Discussion:

When varying the subset-iteration product we can see that the optimal combination is 12 iterations and 12 subsets giving a subset-iteration product of 144. This gave a good recovery coefficient and accurate value of SUV whilst minimising the time required for reconstruction. The wider the gaussian filter width, the worse the recovery coefficient, as this ‘smooths’ the image – creating a better quality image whilst impacting the measured SUV.

Conclusion:

From the standpoint of a purely quantitative measurement, the optimal reconstruction parameters of xSPECT quant would be to use a subset-iteration produce of 144 (12 iterations and 12 subsets) and the gaussian filter function should be turned off. As this reconstruction will not produce a good image quality, this should be used alongside current reconstruction parameters to allow for both visual and quantitative comparisons. Further work from this will be it’s implementation and re-assessment of it’s use in ^{177}Lu-DOTATE therapy monitoring.

Effect of collimator and method of semi-quantification on DaTSCAN striatal binding ratios

Helen Davison and Robyn Cooke
County Durham and Darlington NHS Foundation Trust

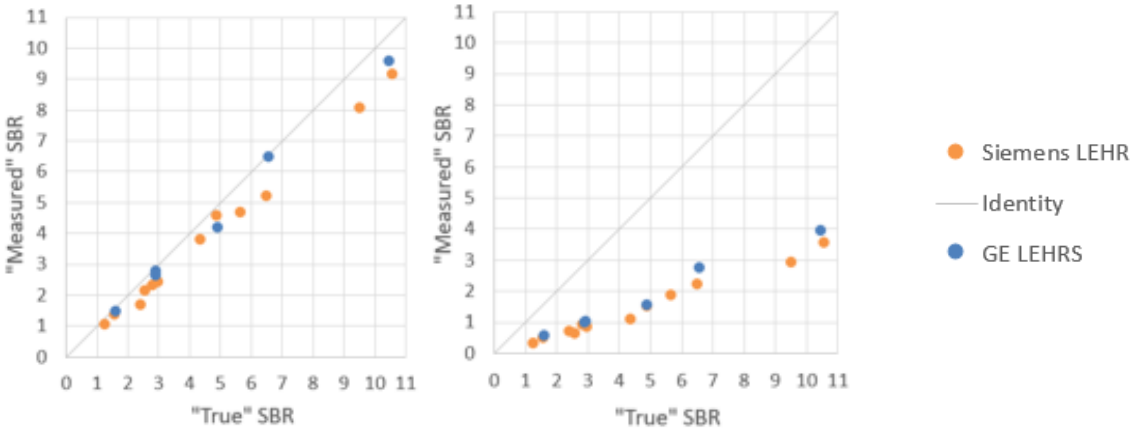
Background: Striatal binding ratios (SBR) are a semi-quantitative measure used to aid interpretation of 123I[Ioflupane] ("DaTSCAN") images. Counts from the whole striatum or intra-striatal regions of interest (ROIs) are compared to background counts using either "tight" ROIs (as in most commercially available programmes such as GE DaTQuant™ proprietary software[1]), or using much larger ROIs with the aim of capturing all striatal counts, avoiding partial volume effects (such as in the Southampton method).

The normal range provided within DaTQuant™ software is derived from a normal database acquired over multiple camera-collimator pairs without calibration, rendering SBR values independent of collimator type. However, new GE LEHRS collimators are not included in the database, and data presented at a DaTQUANT usergroup meeting[3] suggested significant differences in SBR between GE LEHR and GE LEHRS collimators due to the high septal penetration of the latter.

Aim: To test for differences in SBR values between GE LEHRS and Siemens LEHR collimators when measured using GE DaTQuant™ and the Southampton method compared to the "known" SBR value.

Methods: The DaTSCAN phantom was used to measure a range of known SBR values on two gamma camera-collimator pairs: Siemens LEHR and GE LEHRS, following the same methods used for the ENC-DAT calibration[2]. Phantom compartments were gravimetrically filled to give 6 different SBR values. SBRs were calculated using the DaTQUANT™ proprietary software and in-house software that implements the Southampton method. SBR values were compared against the "known" values from gravimetric filling. Quality control of the known SBR values was performed by counting samples of aliquots from each compartment.

Results: There were no statistically significant differences between GE LEHRS and Siemens LEHR collimators when measured using either quantification method. Slightly higher SBR values were found for GE LEHRS than Siemens LEHR collimators, which is unexpected as the Siemens LEHR was expected to have less septal penetration and therefore higher SBR values. The Southampton method results in SBR values much closer to the known values owing to lower loss of counts to partial volume effects, although the loss may be exaggerated in the DaTQuant values since the phantom is not completely clinically representative.



Conclusion: There is no systematic difference between collimators, providing greater confidence for visual and quantitative reporting of DaTSCANS using the new collimators, and allows comparison between patients scanned using the different systems.

Key references

1. Brogley, J. E., 2019, 47(1):21-26. Journal of Nuclear Medicine Technology
2. Varrone A et al. 2013, 40(2):213-27. Eur J Nucl Med Mol Imaging.
3. Woolley G (Hull), 2022, DaTQUANT User Group Meeting (24 May 2022)