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Pre-treatment dosimetry in SIRT: Is it possible to optimize SPECT/CT reconstructions and calculation methods for accurate dosimetry?

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Background: Radioembolization, also known as ^90Y-microsphere selective internal radiation therapy (SIRT) is an effective treatment in unresectable hepatocellular carcinoma (HCC) and metastatic liver cancers. Before ^90Y-SIRT, a treatment simulation is performed by injecting ^99m Tc-macroaggregated albumin (MAA). SPECT/CT images are required to evaluate intra-hepatic ^99mTc-MAA distribution and determine possible extra-hepatic and lung shunt fraction. Additionally, these images are used for ^90Y pre-dosimetry to determine the needed ^90Y activity for treatment. The aim of this study was to optimize the SPECT reconstruction parameters and validate the accuracy of currently applied dosimetric methods in commercial software by developing equivalent in-house dosimetric tools and comparing them with a ground-truth reference method obtained by Monte Carlo simulation.
Methods: Quantitative SPECT/CT reconstructions were assessed on two GEHC cameras using three different phantoms: a uniform phantom, a NEMA IEC phantom, and an anthropomorphic phantom. For the NEMA IEC phantom, three activity concentration ratios between sphere and background (3:1, 8:1, 12:1) were used to mimic clinical conditions. Reconstruction was performed using OSEM with various reconstruction parameters (number of iterations, number of subsets, post-filtering). Impact of the segmentation method was also assessed using different pixel resolutions. Optimal reconstruction parameters were determined using dose-volume histograms (DVH) and image quality metrics (recovery coefficient and roughness). Absorbed dose maps were generated for conventional dosimetry methods (partition model) and 3D dosimetry methods (VSV, LDM) using Python. They were then compared with a reference Monte-Carlo simulation performed with the Gate toolkit. DVH and mean absorbed dose were extracted to evaluate the accuracy of clinical dose-calculation methods.
Results: Best parameters found for dosimetric purposes on GEHC cameras were the following: OSEM with 14 iterations, 10 subsets, and interestingly, with a Butterworth filter. Looking at 3 different pixel samplings (1, 2, and 4 mm), we showed that the most accurate DVH was obtained from segmentation performed with a 1 mm sampling and so SPECT images were systematically resampled to the CT pixel size. With the anthropomorphic phantom, all dosimetry methods reached a good agreement (< 10%) on mean absorbed dose when looking at the liver and the healthy liver volumes. Mean absorbed dose to the lungs could be obtained with a relatively good accuracy (<10%) using a multi-VSV approach. However, the mean absorbed dose to a tumoral lesion (16 mL) was systemically underestimated due to partial volume effects (14-26%). Moreover, all methods showed substantial degradation of the DVH compared to the reference method.
Conclusion: This work showed that 3D dosimetry methods currently used in the clinical context of SIRT might be sufficient to determine mean absorbed doses in the liver. In the case of SPECT images, LDM and VSV perform equally well. However, as image-generated dose maps suffer from the poor spatial resolution of SPECT images, improved accuracy in dosimetry is still challenging.

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