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#9-257 Toward quantitative bremsstrahlung medical imaging by custom gamma camera device

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Radiometabolic therapy is a class of clinical treatments that involves administering radiopharmaceuticals to kill and prevent further development of cancer cells by targeting them at the molecular level. The specificity of this treatment and the possibility of a personalized approach make radiometabolic therapy one of the most promising therapeutic protocol in clinical precision medicine. On the other hand, the effectiveness of the radiometabolic approach depends on maximizing radiation damage to the tumour region while minimizing its potential toxicity on healthy organs and tissues. For that purposes it is important, among other aspects, to be able to quantitatively evaluate the spatio-temporal distribution of the radioactive substance in the patient in order to optimize and personalize the methodology and dosage of radiopharmaceutical. This process involves defining a patient-specific treatment plan, as accomplished in external radiation therapy and brachytherapy. Equally relevant is the determination of the biodistribution of the therapeutic agent during treatment: this would make it possible to evaluate, in post-treatment verification phase, the actual administered dose. This information can be obtained non-invasively, possibly in combination with blood tests or other clinical analyses, by imaging the radiation emitted by the therapeutic radioactive substance, which is capable of escaping from the patient's body. Quantitative analysis of these images permits the estimation of distribution of the radiopharmaceutical isotope activities in each region of interest. The time dependent activity can then be related to relevant radiobiological quantities, in primis absorbed dose.
Performing quantitative imaging in radiometabolic therapy is generally challenging due to different factors, including the peculiarities of involved radionuclides. Moreover, defining and quantifying the volumes of interest are also critical: images in nuclear medicine are functional-based, so the volumes identified from these images do not necessarily correspond to anatomical volumes, which are instead reconstructed in Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). In this context, the bremsstrahlung radiation imaging technique may play an important role for radiopharmaceuticals with (almost) pure β^- (and β^+) emitters, such as yttrium-90 (90Y), used in radiometabolic therapy. While electrons perform their therapeutic task by releasing most of their energy to cells close to the point of radionuclide decay, the bremsstrahlung gamma radiation emitted from the same electrons can escape from the patient and be detected. However, this indirect radiation makes imaging quite complex, especially when administered radiopharmaceutical distribution shall be quantified. In fact, despite initial attempts at quantitative bremsstrahlung imaging dating back to 1980s and improvements on image reconstruction are progressing, clinical exploitation is still at the research level and not yet routinely adopted. Therefore, the main aim of the proposed work has been the setup of an experimental apparatus and methodology to investigate quantitative bremsstrahlung imaging aspects, in order to highlight critical issues and pitfalls, and identify, whenever possible, directions to overcome, mitigate or likely take advantage of some of them. It is worth point out that optimal quantitative imaging reconstruction techniques could be different from those developed for diagnostic. Respect to most of the previous works in this field, we are considering relatively simplified, but as much as possible controlled experimental conditions: well-known emitter activities (90Y), custom gamma camera including readout electronics and reconstruction algorithms; we also minimized attenuation and scattering effects by adopting a simple, small phantom. This approach should help to better disentangle physics and reconstruction effects that contribute to the bremsstrahlung quantitative imaging, allowing for a more straight analysis of potential sources of image degradation and identifying potential improvements. The data acquired on real measurements have been complemented by Monte Carlo simulations and corresponding data analysis, which are then used to produce quantitative assessment but also better evaluate the overall imaging process.
The experimental apparatus and conditions are characterized by the following main components:

- Radionuclide: weighted solution of yttrium-90 Dichloride (90YCl2)

• Portable ENEA-INMRI Triple-to-Double-Coincidence Ratio (TDCR) counter for direct activity measurement on site of the radioactive solution
• Phantoms: two simple PMMA cylinders (40 and 60 mm diameter, 13.9 and 19.7 mm height) with 3 cylindrical cavities each used for the 90Y solution, in the bottom part and a PMMA lid on top.
• Detector consists of a compact, custom gamma camera based on two detection heads with complementary collimators and sizes. The small head includes a pin hole tungsten collimator with 1.2 mm hole diameter, 2 mm thickness, an NaI(Tl) pixellated scintillator with 2 mm pitch, 50 × 50 mm2 active area and 5 mm thickness, optically coupled to a single Hamamatsu H8500 Photomultiplier. The other larger detection head is equipped by a 20 mm thick, 150 × 200 mm2 active area defined by a parallel hexagonal holes lead collimator with 2.1 mm pitch and 0.3 mm septa, a pixellated NaI(Tl) scintillator 1.5 mm pitch, 6 mm thickness coupled to a 3×4 matrix of H8500.
• Monte Carlo simulator is based on Geant4 toolkit.
In the presentation we will details:
• Fine tuning of Monte Carlo simulation parameters
• Definition and analysis of figures of merit on the simulated data for the choice of the reconstruction conditions
• Improved anodic equalization procedures and centroid reconstruction from the experimental data
• First attempt of quantitative determination by simulation-measurement comparisons
• Comparison of the quantitative imaging results with the reference activity provided by TDCR counter.

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