SNMMI SOCIETY OF NUCLEAR MEDICINE & MOLECULAR IMAGING

ANNUAL MEETING

Simulation of Biology-Guided Radiotherapy (BgRT) Treatment Planning and Delivery for Liver Lesions Using Diagnostic FDG-PET/CT Data

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INTRODUCTION

In SCINTIX® biology-guided radiotherapy (BgRT), PET signals are used to guide external radiation beams from the LINAC to the tumor in real time. The RefleXion® X1 system consists of two 90° PET arcs, a 6 MV LINAC, a binary multi-leaf collimator, a kVCT image subsystem, and an MV detector mounted on a fast-rotating slip ring gantry with 60 RPM rotation speed. The PET detectors and LINAC are mounted such that they lie in the same transaxial plane. During treatment delivery, the PET data is reconstructed every 100 milliseconds to generate limited time sampled (LTS) data sets to guide radiation delivery to the tumor.

AIM

In this work, we describe a pre-clinical X1 PET image simulation and BgRT planning system in research mode and demonstrate its ability with diagnostic PET/CT data for patients with hepatic lesions.

METHOD

The pre-clinical PET image simulation system uses diagnostic PET/CT data to simulate RefleXion® X1 system PET data acquired at different stages in the entire BgRT workflow (treatment planning, pre-scan, and delivery). In clinical BgRT workflow, a treatment planning PET scan is first performed on the X1 at multiple bed positions with 10 gantry rotations per bed position and 4 passes. The PET image is used to check activity concentration (AC) and normalized target signal (NTS) values for the tumor and to generate a BgRT plan. A biological tracking zone (BTZ) is defined to encompass the full range of motion of the tumor plus margin. Pre-scan PET images are acquired with 10 gantry revolutions per bed position and a single pass. In delivery, LTS PET images were reconstructed every 100 ms with preceding 500 ms data acquisition. Image degradation factors such as scatter, randoms and detector efficiencies are modelled in the simulator and have been previously validated with measurements. To demonstrate system capability, we used diagnostic PET-CT dataset from a patient injected with 389 MBq of FDG activity as a less-than-ideal scenario, since 555 MBq of injected activity is recommended in clinical BgRT planning and delivery. While an iterative reconstruction algorithm with scatter correction was used in reconstructing diagnostic PET images resulting in a higher contrast, filtered back-projection was used in the BgRT PET simulation system so that the results are linear and unbiased.

RESULTS

The treatment planning, pre-scan, and delivery PET images from the X1 machine were successfully simulated on the pre-clinical PET image simulation system for six cases. Figure 1 shows simulated pre-scan images for a representative hepatic lesion.

The minimum, maximum, and mean activity in the hepatic tumor was 12 kBq/ml, 46 kBq/ml, and 30 kBq/ml in the diagnostic PET while they were 17 kBq/ml, 25 kBq/ml, and 21 kBq/ml in the simulated treatment planning X1 PET images. The mean background activity was 11.4 kBq/ml and 12.4 kBq/ml in the diagnostic and simulated planning PET images, respectively. The simulated treatment planning X1 PET images were used to check AC and NTS values for eligibility of SCINTIX treatment planning. For this representative case, AC and NTS were found to be 12.98 kBq/ml and 9.83, respectively, which met SCINTIX treatment criteria.

Based on the simulated treatment planning PET image, a BgRT plan was created to deliver 36 Gy in 4 fractions to the hepatic lesion. The simulated delivery plan predicted a treatment time of less than 15 minutes. The conformality index (CI) for the planning target volume was 1.12.

Pre-scan and delivery PET images were subsequently simulated. The AC values were 15.6 kBq/ml and 13.07 kBq/ml, and the NTS values were 8.85 and 9.32 in the pre-scan and delivery PET images, respectively. All the AC and NTS values in the simulated PET images met BgRT treatment planning and delivery criteria. PET-guided treatment deliveries were simulated with PET imaging data from the simulated pre-scan and delivery PET data, respectively. The CI for the planning target volume in simulated deliveries was 1.17, and 1.13 based on simulated pre-scan and delivery PET data, respectively. Figure 2 compares dose profiles in the treatment plan and simulated deliveries.

The expected gross target volume (GTV) coverage by the prescription dose was 100% in both the treatment plan and simulated deliveries.

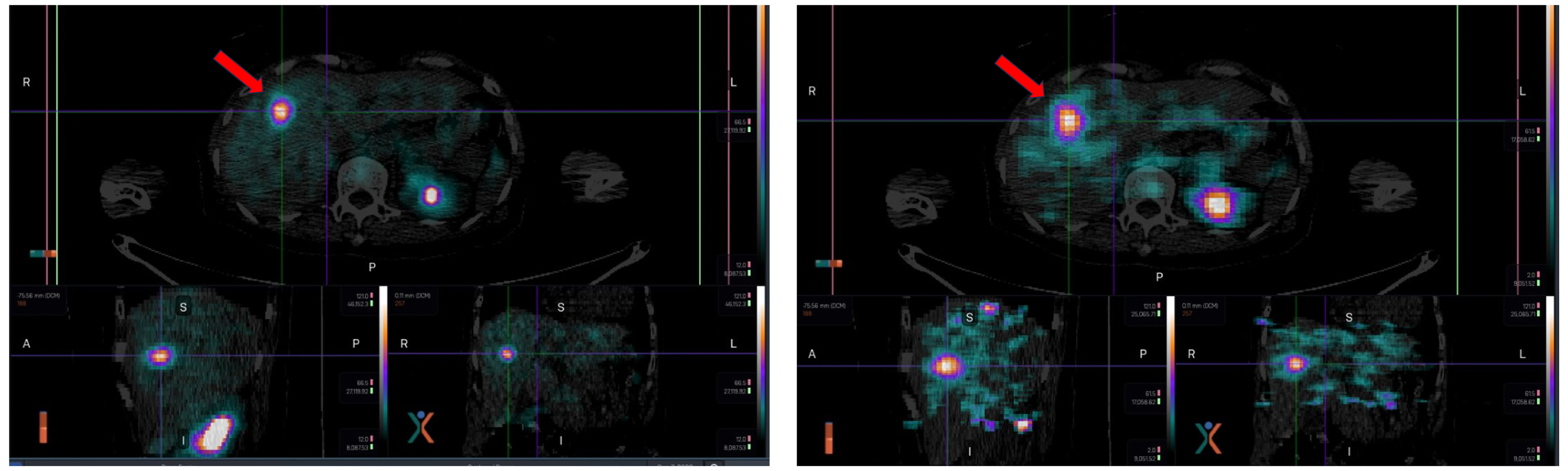

Figure 1: Comparison between PET images in the axial, sagittal, and coronal views for a PET-positive hepatic lesion in a diagnostic PET/CT scan image (left) and the simulated pre-scan PET image from the RefleXion X1 machine (right). The red arrow indicates the location of the hepatic lesion.

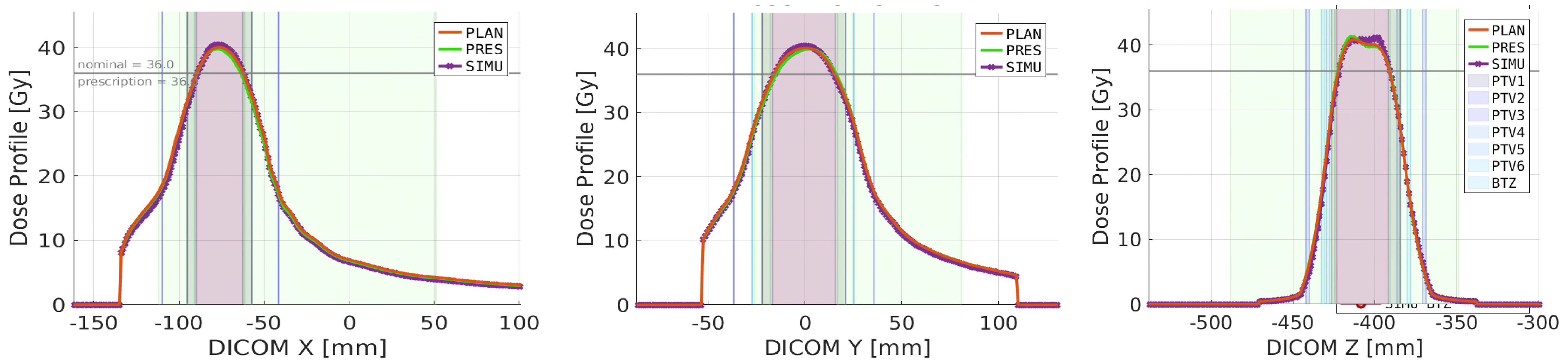

Figure 2: Comparison of dose profiles in three orthogonal directions. The red curves are the BgRT treatment plan dose, the green curves are simulated delivery dose based on simulated pre-scan PET images, and the purple curves are simulated delivery dose based on simulated delivery PET images.

CONCLUSIONS

1. This work demonstrates successful simulation of PET images acquired in different stages of the BgRT treatment planning and delivery workflow based on diagnostic PET-CT data. This simulation system could be used to evaluate BgRT treatment feasibility with diagnostic PET images instead of requiring the patient to undergo treatment planning PET scans on the X1 machine. It also provides predictions of pre-scan and delivery PET images in treatment delivery workflow to ensure adequate PET strength in SCINTIX delivery.
2. In addition, this study demonstrates the feasibility of BgRT for FDG PET-positive liver lesions. With PET signal guidance, both patient setup and internal organ motion uncertainties could be reduced in treatment of hepatic lesions with adequate PET signal strength.

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