Patient-specific in-vivo QA in MRGRT: 3D EPID dosimetry for the Unity MR-linac

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SUMMARIES

9.1. Summary:

Radiotherapy treatments need adequate quality control (QC) to ensure a correct delivery of the prescribed dose to the target area. One of the most extended safety nets for treatments in conventional radiotherapy machines is in-vivo EPID dosimetry, which uses the dose acquired by an Electronic Portal Imaging Device (EPID) during treatment to accurately reconstruct the dose as it was delivered to the patient. Once EPID images are back-projected into the patient geometry, a comparison in 2D or 3D with the dose distribution from the treatment planning system can be performed. To quantify potential differences gamma analysis is performed Gamma analysis is a method to identify not only differences in dose but also in distance between two 2D or 3D maps. This serves medical physicists to determine whether the delivered dose is within acceptance parameters or not, and in that case, take actions.

In this work we developed a method to validate radiotherapy treatments delivered on a novel system: the Unity MR-Linac. This machine, which combines a radiation source (linac) and an imaging device (MRI), will help to irradiate tumors more accurately by means of a new range of techniques only available thanks to the image guidance of the MRI during irradiation. The verification of such treatments can be performed by using images of the delivered beam captured by an EPID situated opposite to the radiation source, behind the cryostat of the MRI scanner. This project focuses on the adaptation of an already existing algorithm used with conventional linacs to the new physics and design characteristics of the Unity MR-linac. The main challenge for this adaptation is the presence of the MRI scanner between the patient and the EPID, acting as a secondary source of scatter and as an attenuation medium for the beam.

Chapter 2 describes the first step of the project, aimed to create a model to account for the extra scatter and attenuation measured by the panel when the photon beam irradiated by the linac traversed a mock-up of the MRI scanner consisting of a structure of 11 cm of aluminum. The parameters of the adapted algorithm were estimated by fitting EPID data to ionization chamber (IC) dose measurements for different set-ups both with and without the aluminum structure. Validation of the modified model was performed in 2D using 58 IMRT fields delivered to a slab phantom, with and without the aluminum mock-up. EPID reconstructed dose distributions were compared to planned dose distributions using the γ-evaluation method. The γ_{mean} obtained with the adapted projection algorithm was similar to that obtained with the conventional method. Dose profiles of several square fields reconstructed with our adapted algorithm showed excellent agreement when compared to TPS.

In Chapter 3 a characterization study of the EPID in the Unity MR-Linac was performed to validate the feasibility of using the panel as a dosimeter . A series of EPID images and IC measurements were used to study the effects of the magnetic field, the scatter generated in the MR housing reaching the EPID, and the inhomogeneous attenuation from the MR housing. Dose linearity and dose rate dependence were also determined. All these results were compared to the performance of similar EPID panels on conventional linacs to assess the differences (if any) of the dose-response characteristics of the panel. The results indicated that the magnetic field at the EPID level, dose rate dependence, and dose linearity show similar results compared to conventional linacs. However, it was found that gantry angle-dependent behavior of beam attenuation and scatter would pose serious challenges for the implementation of 3D in vivo dosimetry.

The first proof of concept of the complete modified algorithm was

demonstrated in **Chapter 4**. Making use of the results of Chapter 2 and 3, proper adaptations in the physics modelling to accommodate for the aforementioned challenges of the Unity MR-linac, were made. To validate the method, 25 IMRT beams were irradiated at 3 cardinal gantry angles (0º, 90º, 180º) and the EPID images acquired during delivery were back-projected to the isocenter plane. The 2D reconstructed dose distributions were compared to dose measurements using the 2D OCTAVIUS 1500 IC array (PTW, Freiburg, Germany). A method to account for the gantry-angle dependence due to the geometry of couch, bridge and cryostat was introduced.

In **Chapter 5** all the necessary ingredients for 3D in-vivo EPID dosimetry were combined and a functioning environment for radiotherapy treatment verification in the Unity MR-linac was presented. Furthermore, a direct comparison of the reconstructed dose distributions to the treatment planning system was performed. The method was first validated using data from clinical treatments of 5 patients (2 rectal cancer, 2 prostate cancer and one patient with an oligo metastasis). 'In-air' EPID images were acquired and used to reconstruct the 3D dose distributions which were compared against planned and measured (with the Octavius 4D system) dose distributions. Pre-treatment verification against TPS data showed $y_{mean} = 0.41 \pm 0.04$ and $y_{passrate} = 98.4 \pm 0.1$. The comparison against the OCTAVIUS 4D system showed $y_{mean} = 0.37 \pm 0.09$ and $y_{passrate} = 97.4$, 90% CI [95.2, 99.7]. In short, it was demonstrated that 3D dosimetric verification of Unity MR-linac treatments using portal dosimetry is feasible, pre-treatment as well as *in-vivo*.

The project so far has focused on dose reconstruction in the central part of the beam, with homogeneous attenuation, However, a remaining problem was to accurately reconstruct the dose in the lateral areas of strong and inhomogeneous attenuation. To solve that problem, a

study was performed in **Chapter 6** on the implementation of a deep convolutional neural network that corrects for the artifacts in the 2D dose images. A dedicated U-Net of EPID reconstructed images at the isocenter was trained using the corresponding TPS 2D dose images as ground truth. The clinical validity of the U-Net corrected dose images (the so-called DEEPID dose images) was assessed with in vivo verification data of 45 large rectum IMRT fields. Results showed that the use of DEEPID allows for accurate dose reconstruction using the entire EPID frame, thus enabling dosimetric verification for field sizes up to ~19 × 22 cm2 at isocenter.