Computational Model to Simulate the Interplay Effect in dynamic IMRT delivery

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Abstract. The purpose of this study was to develop and experimentally verify a patient specific model for simulating the interplay effect in a DMLC based IMRT delivery. A computational model was developed using MATLAB program to incorporate the interplay effect in a 2D beams eye view fluence of dynamic IMRT fields. To simulate interplay effect, the model requires two inputs: IMRT field (DMLC file with dose rate and MU) and the patient specific respiratory motion. The interplay between the DMLC leaf motion and target was simulated for three lung patients. The target trajectory data was acquired using RPM system during the treatment simulation. The model was verified experimentally for the same patients using Imatrix 2D array device placed over QUASAR motion platform in CL2100 linac. The simulated fluences and measured fluences were compared with the TPS generated static fluence (no motion) using an in-house developed gamma evaluation program (2%/2mm). The simulated results were well within agreement with the measured. Comparison of the simulated and measured fluences with the TPS static fluence resulted 55.3% & 58.5% pixels passed the gamma criteria. A patient specific model was developed and validated for simulating the interplay effect in the dynamic IMRT delivery. This model can be clinically used to quantify the dosimetric uncertainty due to the interplay effect prior to the treatment delivery.

1. Introduction

Intensity Modulated Radiation Therapy (IMRT) is a state of art treatment modality in many complex sites. IMRT technique is an effective tool to achieve dose escalation with high conformal dose distribution around the target. Dose escalation is an essential process for lung cancers to increase the survival rate. But, the delivery of IMRT in lung is not considered in most of the clinics due to the respiratory motion of target which produces dosimetric errors in the delivery, especially when using Dynamic Multi Leaf Collimator (DMLC). These dosimetric errors are caused by blurring of dose and interplay between tumour motion and DMLC motion. The interplay motion can be divided into two orthogonal motions; parallel interplay motion where the target motion is parallel to DMLC motion; perpendicular interplay motion where the target motion is perpendicular to DMLC motion.

Various studies investigated the dosimetric uncertainties due to the intra-fractional respiratory motion of tumour. Most of the studies concluded that the respiratory motion induced dosimetric uncertainties were larger for single filed or fractions and averaged out over the entire fractions (1-5); whereas one may expect significant errors in small fraction treatments such as stereotactic body radiation therapy (SBRT). However, this effect may be different for different patient respiratory parameters such as breathing amplitude, phase and period. Advanced techniques such as gating and tracking (6-13) can be employed to reduce these dosimetric uncertainties. Use of these techniques is encouraged only if considerable dosimetric uncertainties are expected over the entire treatment fractions. In order to have an idea about the dosimetric uncertainties due to interplay effect, a patient specific model is necessary.

Therefore the purpose of this work was to develop a patient specific computational model to simulate the parallel interplay effect in the delivery of dynamic IMRT.
2. Materials & Methods

2.1 Computational Model

A computational model was developed to simulate the dosimetric uncertainty introduced by parallel interplay effect in a two dimensional (2D) beams eye view (BEV) fluence of a dynamic IMRT field. This model was implemented in MATLAB (ver 7.0). The model requires two inputs; dynamic IMRT field (along with MU and dose rate information) and patient specific respiratory motion of target at BEV. Model extracts MLC leaf positions and fractional MU of each control point from the inputted DMLC file and by using this information original velocity ($V_{MLC}$) of each DMLC pair was calculated. The velocity of moving target ($V_{tar}$) was calculated using the patient specific respiratory motion. The interplay motion of target was incorporated into DMLC leaf motion by modifying the velocity of DMLC leaf pair ($V_{Res}$) as follows

\[
V_{Res} = \begin{cases} 
V_{MLC} - |V_{tar}| & \text{for } V_{tar} > 0 \\
V_{MLC} + |V_{tar}| & \text{for } V_{tar} < 0 
\end{cases}
\]

The model subtracts the velocity of the moving target ($V_{tar}$) with $V_{MLC}$ during the forward (positive) direction of target motion (i.e. both the target and DMLC are moving in the same direction). Conversely, the program adds the $V_{tar}$ with the $V_{MLC}$ during backward (negative) direction of target motion (i.e. both the target and DMLC are moving in opposite direction). During the forward target motion, the resultant direction of leaf motion is: towards backward when $V_{tar}$ is greater than $V_{MLC}$ ($V_{Res}$ = negative) and towards forward when $V_{tar}$ is less than $V_{MLC}$ ($V_{Res}$ = positive). The model finally derives the 2D BEV fluence for this modified DMLC file at isocenter.

2.2 Experimental Verification:

To demonstrate the functionality of this model, the interplay effect was simulated for dynamic IMRT plans of three lung patients. These plans had seven fixed fields and generated for a total dose of 60Gy in 30 fractions with 6MV X-ray photon beam at a dose rate of 400 MU/min using a commercial treatment planning system (Eclipse™, Varian Medical Systems, Palo Alto, CA). The DMLC leaf motions were calculated using leaf motion calculator (LMC- ver 8.6). Patient respiratory motion was acquired using Real-time position management (RPM) system (Varian Medical Systems, Palo Alto, CA). The RPM system uses a marker block and infrared camera to capture the chest movement of patient. It was assumed that the external surrogate - marker block motion simulated the internal tumour motion. Figure 1 shows the respiratory motion of a patient acquired using RPM system. Using the RPM generated file, the velocity of target along the DMLC motion direction was derived. LMC calculated DMLC leaf motions along with MU and dose rate information were imported into the model and the velocity of the each DMLC leaf pair was modified. The 2D BEV fluence at isocenter was derived using the modified DMLC file. This process was repeated for each patient.
To test the accuracy of this model, the experimental verification measurements were carried out in a medical linear accelerator (CL2100CD, Varian Medical Systems, Palo Alto, CA) equipped with millennium 120 DMLC system. The experimental setup of dosimetric verification is shown in Figure 2. The original dynamic IMRT plan was delivered on a moving Imatrixx 2D ion chamber array device (Scanditronix Wellhöfer, Freiberg, Germany) which was sandwiched between perspex slab phantoms. QUASAR motion platform (Modus Medical Devices Inc., Canada) was used to move the Imatrixx device. The RPM generated patient respiratory motion file was imported into the QUASAR motion platform software to simulate the patient specific motion. In order to simulate the parallel interplay effect, the Imatrixx device motion direction was kept along the DMLC leaf motion.

The model simulated fluence and experimentally measured fluences were compared with the TPS static fluence using an in-house developed gamma evaluation program with 2\% dose difference and 2\text{mm} distance to agreement criteria.
3. Results & Discussion

Figure 3 show the 2D BEV fluence of a static IMRT field exported from TPS. Figure 4 show the computational model simulated 2D BEV fluence (interplay effect introduced). Figure 5 shows the gamma comparison of static fluence with model simulated delivered fluence.

The simulated results were well agreement with the measured (table 1). Average percentage of pixels passed the gamma criteria were 59.3% & 57.6% for simulated and measured fluences.
| Patient Number | Measured % | Simulated % |
|---------------|------------|-------------|
| 1             | 55.3       | 58.5        |
| 2             | 53.3       | 59.2        |
| 3             | 64.2       | 60.2        |

Studies were already attempted to develop automatic computational models to simulate the interplay effect in dynamic treatment delivery. Mohn et al. (14) developed a model for evaluating the dosimetric effects of interplay effect in dynamic IMRT dose delivery. Their model was able to calculate the three dimensional (3D) dose distributions both with and without the interplay effect. Jensen et al. (15) developed a 4D computational tomography (CT) Monte Carlo simulation method for accounting the respiratory motion induced interplay effect in step-shoot IMRT using the MLC controller delivery log files. Rao et al. (16) studied the dosimetric impact of respiratory motion in SBRT; they used deformable image registration to calculate the 4D dose distributions. In this present study, we also developed a computational model for simulating the dosimetric effect of interplay in dynamic IMRT delivery. Instead of using the 3D/4D CT data set, we directly modelled the interplay effect in the 2D BEV fluence. This method provides a reasonable estimation of dosimetric uncertainties due to interplay effect with trivial calculation time. The proposed model could simulate only parallel interplay effect, but for complete uncertainty evaluation 3D model is required.

4. Conclusion

A patient specific model was developed and validated for simulating the interplay effect in the dynamic IMRT delivery. This model can be clinically used to quantify the patient specific dosimetric uncertainty due to the interplay effect prior to the treatment delivery.

5. Reference

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