Dose engine verification of a dual-level mMLC-based TPS CrossPlan benchmarked by MCNPX and Pinnacle

Yaxi Liu [1, 2*], *Chengyu Shi* [1, 2], *Sotirios Stathakis* [1, 2], *Niko Papanikolaou* [1, 2]

Cancer Therapy & Research Center, San Antonio, TX 78229, U.S.A [1]

University of Texas Health Science Center at San Antonio, San Antonio, TX, 78229, U.S.A [2]

Purpose: To evaluate and verify a dose engine by comparing the three-dimensional dose matrix calculated by dual-level micro multileaf collimator based TPS and a Monte Carlo-based code MCNPX. **Method and Materials**: An irregular aperture shape was created by a dual-level mMLC and dose was delivered through the aperture to a cylindrical solid water phantom by a 6MV Varian 600C linear accelerator. A Monte Carlo model was designed by using MCNPX according to the configurations of the linac source, jaws, aperture shape and phantom. The computed dose matrix from CrossPlan treatment planning system (TPS) and MCNPX was compared against each other and the radiographic films. The isodose distributions, profiles, and gamma index were selected for comparison parameters. 3D dose matrixes from CrossPlan and MCNPX were converted and exported to Pinnacle TPS for further comparison. **Results**: The planar dose image generated by both CrossPlan and MCNPX provided close match with each other considering the isodose overlay, dose profiles. The mean dose difference was less than 1.4%, and the gamma index values were less than one. The computed dose images from CrossPlan and MCNPX matched well with the radiographic films in isodose lines. The isodose and DVH comparisons by Pinnacle3 further demonstrate the agreement of the 3D dose matrix from CrossPlan and MCNPX. **Conclusion**: The good agreement between the computed dose from CrossPlan and MCNPX compared with the radiographic films indicated that both CrossPlan and MCNPX dose engines are capable to calculate and provide reliable and reasonably accurate dose distribution. The CrossPlan based dual-level micro-MLC is capable of precise aperture shaping, potentially allowing for an improved intensity modulated radiation therapy (IMRT) planning and delivery.

Conflict of Interest: Supported by Initia Medical Technology

Introduction

Multi-leaf collimators (MLC) have become the standard of radiotherapy practice in recent years, both because they can replace conventional blocks and also because when operated in a dynamic mode, they allow for intensity modulated radiation therapy (IMRT) delivery. MLC has an important role in IMRT treatment since the IMRT treatment plan uses the MLC to convert an ideal intensity map into a deliverable intensity map [1]. Historically, MLCs have one-dimensional in the motion, traveling along the axis of one of the two machine jaws. During the conversion, due to the MLC dimension limit and direction limit, some apertures may not be able to shape in one segment. Thus, multi-segments are needed and there are field junctions among different segments, which will cause either over-dose or under-dose in the junction region. We have recently installed a dual-level micro MLC that has MLC leaves in orthogonal direction. With a special designed four-bank, bi-direction micro-MLC (mMLC) [2], almost any kind of aperture shape can be shaped in one segment in radiation field. Therefore, the mMLC can improve the quality of an IMRT plan. At the same time, the dose calculation algorithm, makes important contributions to the dose estimation, dose delivery during commissioning the mMLC, therefore, it is important to use other accepted dose calculation algorithm to double check the treatment planning system. Monte Carlo code, MCNPX [3] is a good candidate for this verification. In this study, a special aperture was designed and 3D dose matrix was generated by MCNPX and CrossPlan [4], a dual-level mMLC-based treatment planning system (TPS).

* Corresponding author: Department of Radiation Oncology, Cancer Therapy & Research Center, San Antonio, TX, 78229, USA. Tel: +12104501658; Fax: +12106165682; E-mail address: yliu@ctrc.net (Y. Liu)

Materials and Methods

The mMLC, as shown in Figure 2(b), named as AccuLeaf micro multileaf collimator [2], has 96 tungsten leaves divided by four banks, each group consisting 24 leaves. The 4-bank MLC is composed by two parallel levels perpendicular to the central axis, and the leaves travel direction for one level is perpendicular to the other level. Each level has two opposite MLC group. Each leaf has a height of 37.5 mm and a physical length of 60 mm. It provides the capability of precision aperture shaping and high resolution by offering micro leaves with width as 2.1mm and operating in two orthogonal directions. The maximum field size of the DmMLC is 97mm x 108mm formed by total 96 leaves.

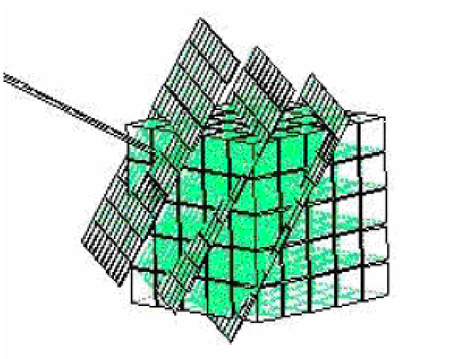

Figure 1: Description of dose algorithm by three dimensional grid

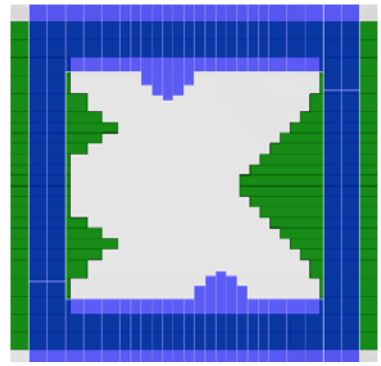

Figure 2 (a): BEV aperture shape with dual-level mMLC

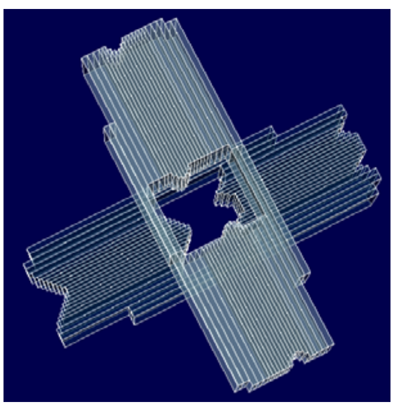

Figure 2(b): dual-level bi-directional 4-bank micro multileaf collimator.

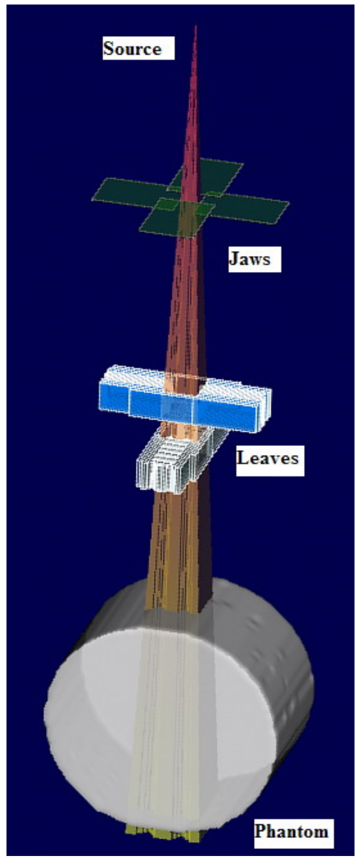

Figure 3: System configuration for the test pattern

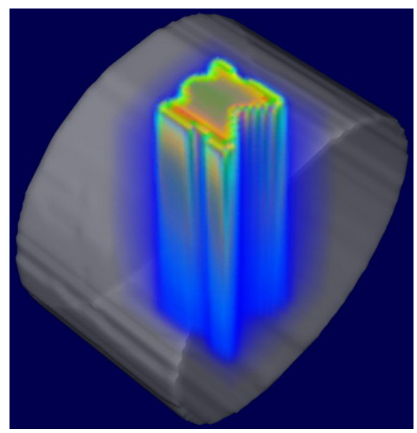

Figure 4: 3D Dose intensity map inside the phantom by CrossPlan

CrossPlan radiation treatment planning system

The dose calculation engine of CrossPlan is based on a 3D-grid in the patient coordinate system. This grid consists of small cubic cells (3D-cells) with a dose value is assigned to each one. For each beam orientation, the treated volume in the beam coordinate system is divided into 2D-layers by parallel planes (layers) perpendicular to the beam axis as Figure 1. The layers are divided into 2D cells. The dose value is calculated at each cell of every layer in the beam coordinate system.

A special aperture shape was designed as Figure 2(a), with two equilateral triangles, two half circles and a right triangle. Figure 2(b) showed the beam-eye-view of the aperture shaped by the four-group mMLC. The source was 6MV photon beam from Varian 600C with jaws, and mMLC and a cylindrical solid waster phantom configured as Figure 3. A single beam was used and the dose calculation result by CrossPlan for 3D dose distribution was shown in Figure 4.

Monte Carlo modeling and dose simulation

MCNPX is a general-purpose Monte Carlo radiation transport code for modeling the interaction of radiation with everything. MCNPX stands for Monte Carlo N-Particle eXtended. It extends the capabilities of MCNP4C3 to nearly all particle types and to nearly all energies. MCNPX is fully three-dimensional and time dependent. MCNPX simulates the radiation transport interaction and tracks the particle flux, eventually convert flux to dose. MCNPX has rapidly developed into a significant Monte Carlo simulation tool for various applications in the low-energy and high-energy transport fields with applications in radiation, medical accelerator and nuclear medicine. Recently there are raising interests of applying MCNPX in the fields of electron and photon therapy in medical physics, accelerator-based radiography imaging technology.

The dose calculation in MCNPX is to track the particle distribution and obtain the flux of the studied particles. With the mesh and grid, the flux distribution inside a target can be obtained in small 3D cell. The mesh tally function is an advanced feature from MCNPX, which graphically displays particle flux, dose, or other quantities on a rectangular, cylindrical, or spherical grid overlaid on top of the standard and irregular geometry. Any irregular geometry can be covered by a cube and then the cube divided by thousands or millions smaller cube. Particles are tracked through the independent mesh cell.

A detailed Monte Carlo model was designed according to the configuration of source, jaws, mMLC and phantom as in Figure 3. The normalized dose map was obtained with processing the data from MCNPX simulation. The 3D dose intensity map at the various slice view was shown in Figure 5.

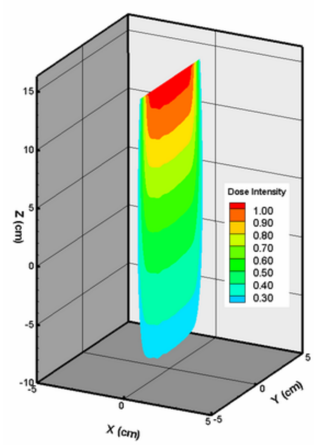

Figure 5 (a): Single-slice (at X=0 plane) view of 3D dose intensity map by MCNPX

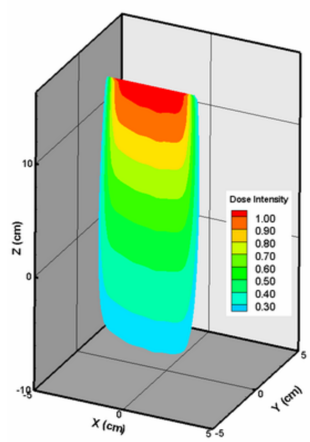

Figure 5(b): Single-slice (at Y=0 plane) view of 3D dose intensity map by MCNPX

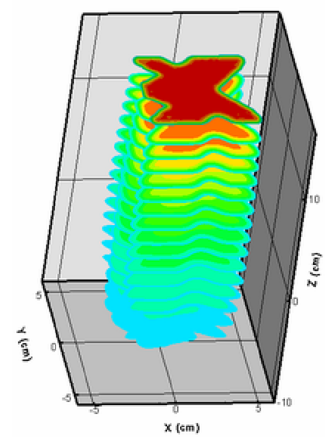

Figure 5(c) Multi-slice view of 3D dose intensity map calculated by MCNPX

Results and Discussion

To analyze the 3D dose matrix, at first, 2D planar dose images at the same position were obtained from the 3D dose intensity map by CrossPlan and MCNPX. The normalized 2D planar dose images from CrossPlan, MCNPX simulation, and delivered dose on EDR2 film (Eastman Kodak Company, Rochester, NY) were shown as figure 6. The selected comparison output method of 2D dose intensity map includes isodose overlay, dose profiles and gamma analysis [5]. The gamma value was given as a combination of dose subtraction and distance-to-agreement (DTA) of each pixel in the reference image.

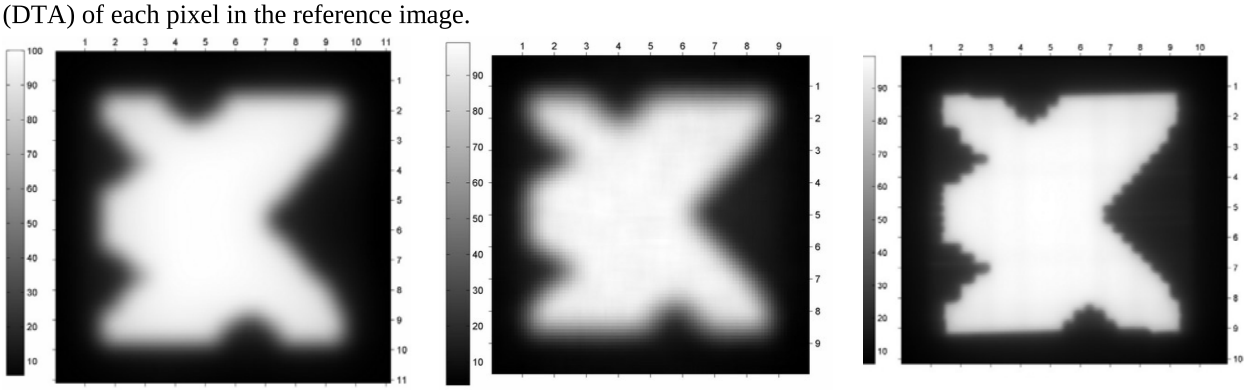

Figure 6. 2D dose intensity map by CrossPlan (left), MCNPX (middle), and EDR2 film (right) at the middle position of solid phantom

The computed dose images, including the CrossPlan calculated image and MCNPX simulated image were compared with the radiation image. Isodose overlay was selected as the comparison output method by using the radiation image tool, RIT113 Version 4.4(Radiological Imaging Technology, Colorado Springs, CO). The isodose overlay was shown in figure 7 (a)-(c) with comparison among CrossPlan, MCNXP and EDR2 films. Monte Carlo result shows slightly closer match with film for the isodose lines.

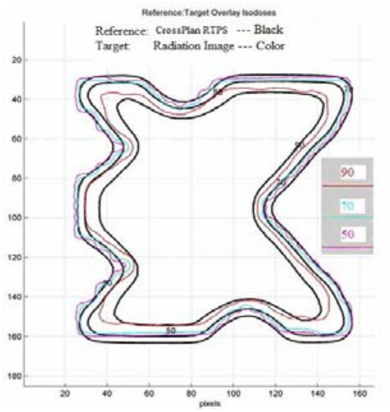

Figure 7. Isodose lines by CrossPlan and Film

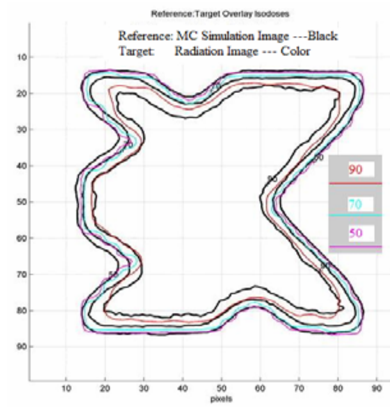

Figure 7. Isodose lines by MC and Film

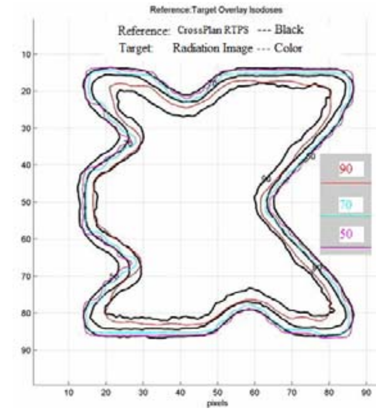

Figure 7. Isodose lines by MC and CrossPlan

Besides the isodose overlay, the dose profiles and gamma index were selected to compare the computed images, as shown in Figure 8(a)-(c).

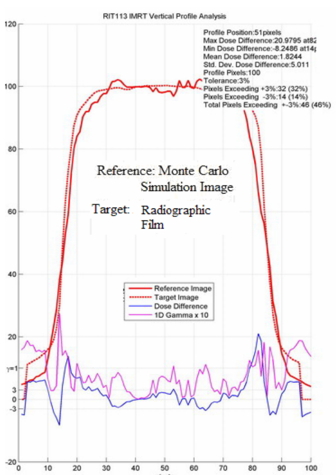

Figure 8(a): Dose horizontal profile of MCNPX and EDR2 film

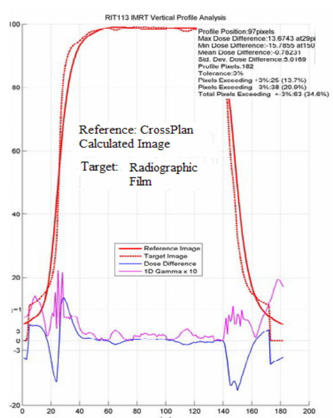

Figure 8(b): Dose horizontal profile of CrossPlan and EDR2 film

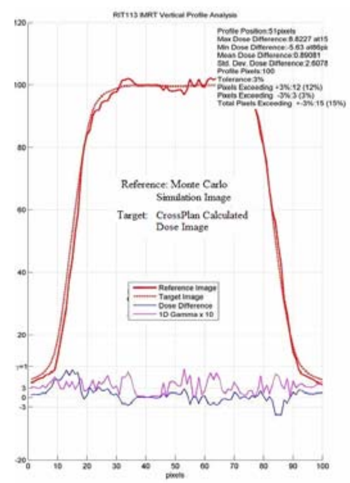

Figure 8(c): Dose horizontal profile of MCNPX and CrossPlan

The horizontal profiles provide a close match in the dose images from MCNPX and CrossPlan. The mean dose difference was 0.9% with less than 15% of dose difference exceeded the tolerance 3% and gamma value was less than one.

Comparison of 3D dose matrix comparison by CrossPlan and MCNPX in Pinnacle3

To export the 3D dose matrixes calculated by CrossPlan and MCNPX to the widely accepted TPS Pinnacle3, two trials based on one patient setting was created. A dose conversion and transfer toolkit was developed exclusively for the further comparison of CrossPlan and MCNPX 3D dose matrixes. The isodose lines from the transverse view, sagittal view and coronal view as Figure 8(a)-(c) are closely matched each other except the slight dose undulation from MCNPX. The dose undulation comes from the uncertainty of Monte Carlo simulation and can be smoothed with higher history of simulation. In the region of interest (ROI) analysis of dose value histogram (DVH) as Figure 8(d), the maximum dose difference was less than 1.0% and the mean dose difference was less than 3.0%.

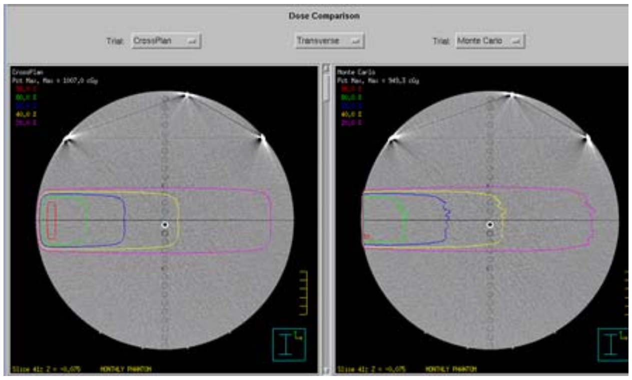

Figure (a): Dose Comparison of CrossPlan and Monte Carlo with Transverse view in Pinnacle3

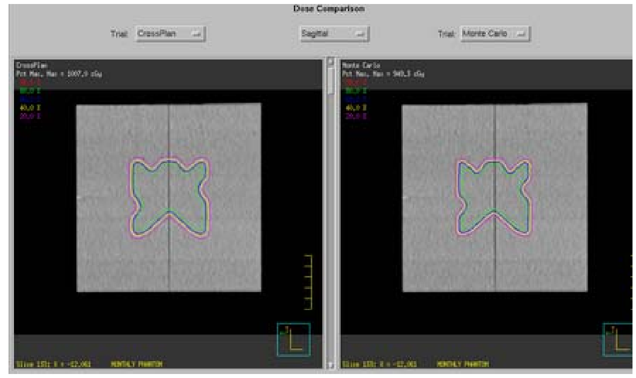

Figure (b): Dose Comparison of CrossPlan and Monte Carlo with Sagittal view in Pinnacle3

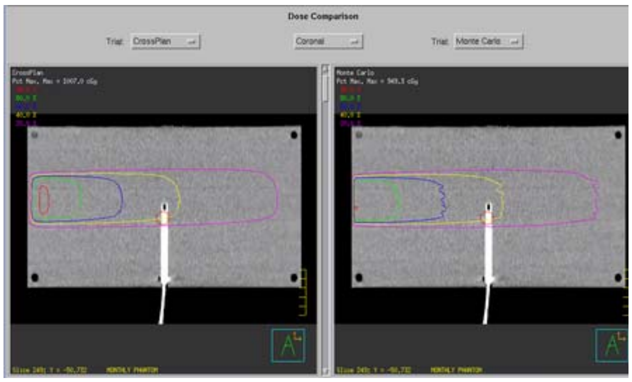

Figure (c): Dose Comparison of CrossPlan and Monte Carlo with Coronal view in Pinnacle3

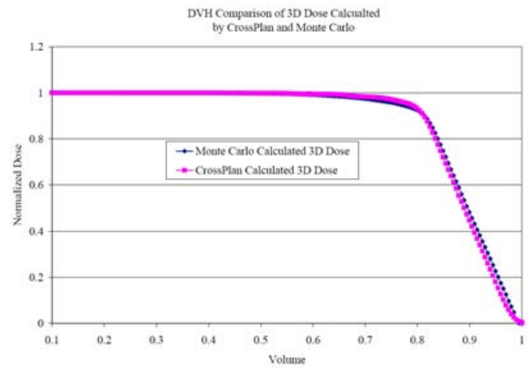

Figure (d): DVH Comparison of CrossPlan and Monte Carlo in Pinnacle3

Both CrossPlan and MCNP dose calculation gave accurate dose estimation when comparing to the EDR2 film. CrossPlan treatment planning system is for clinical use and for the commissioning of the dual-level mMLC even though its dose calculation may not be as accurate as the MCNPX if Monte Carlo simulates enough history. The mMLC has the ability to shape complex aperture shape in one segment without field junction, which has the advantage to deliver more conformal dose to the target for an IMRT treatment plan.

Conclusion

In this study, a preliminary evaluation of dose engine comparison has been carried out with an innovative bi-directional dual-level mMLC. The 2D dose intensity maps from CrossPlan, MCNPX and EDR2 films give reasonable agreement in terms of isodose overlay and gamma value. The 3D dose matrix comparison in Pinnalce3 offers further verification about the 3D dose calculated by CrossPlan and MCNPX. The dual-level mMLC provides the capacity of accurate shaping for complex aperture. With the special aperture shape designed in this study, MCNPX has shown the efficiency and effectiveness for complicated shape modeling. The dose images generated by both CrossPlan and MCNPX provided pretty close matches with each other considering the isodose overlay, dose horizontal profile and gamma analysis. The good agreement between the computed dose images from CrossPlan and MCNPX comparing against the radiographic films indicated the reliability and accuracy of dose engine provided by CrossPlan and MCNPX.

References

[1] Boyer A., etc.., “Basic applications of multileaf collimators. Report of task group No. 50 radiation therapy committee”, American Institute of Physics for the AAPM, New York, NY (2001).

[2] M. Bucciolini, S. Russo, F. Banci Buonamici, S. Pini, and P. Silli, “Dosimetric characterization of a bi-directional micro multileaf collimator for stereotactic applications,” Med. Phys. **29**: 1456-63 (2002).

[3] Waters L., “MCNPX 2.4.0, Monte Carlo N-Particle code,” Los Alamos National Laboratory, New Mexico, USA, LA-UR-02-5253 (2002).

[4] Initia Medical Technologies, “AccuSoft V4.03, Treatment Planning System”, Initia Medical Technologies, Israel, Operation Manual 02-ATPA-122, (2006)

[5] D. A. Low,W. B. Harms, S. Mutic, and J. A. Purdy, “A technique for the quantitative evaluation of dose distributions,” Med. Phys., Vol. **25**, May 1998, pp 656-661.