Towards instantaneous, patient specific, measurement-based pre-treatment QA via integrated machine learning of trajectory files and EPID-based MLC QA

DukeHealth

L. Lay [1], J. Adamson [1], W. Giles [1], K. Chuang [2]
1. Department of Radiation Oncology, Duke University, Durham, NC 27710
2. Department of Radiation Oncology, Duke Kunshan University, Jiangsu, China, 215316

JULY 12–16 2020 VIRTUAL
Improving Health QUALITY. Increasing Global IMPACT
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

- The current standard for pre-treatment QA is time-consuming, ineffective at identifying common problems in the treatment plan [1], and incompatible with innovative radiotherapy techniques such as online adaptive radiotherapy (OART) [2-3].
- We recently developed a machine learning algorithm to predict multi-leaf collimator (MLC) discrepancies based on LINAC trajectory log files. The model is applicable to dose-volume histogram (DVH) based pre-treatment QA, and can be carried out virtually after treatment planning, thus being applicable to OART.
- One weakness of this prediction-based pre-treatment QA model: the trajectory file only records discrepancies measured by the linear accelerator itself.
- Our methodology accounts for all MLC discrepancies by: 1) measuring uncertainty in pre-defined dynamic MLC motion, and 2) quantifying uncertainty with EPID images

AIM

The study aims to develop a patient specific QA technique (Figure 1) that:

- provides instantaneous feedback after treatment planning, increasing OART compatibility
- can provide DVH-based feedback for clinically relevant plan analysis
- incorporates measured MLC uncertainties from a novel set of EPID based measurements that can be carried out at regularly (weekly, daily, etc.)

METHOD

Summary:

This study is divided into two steps: (1) develop the EPID based method to measure MLC error unaccounted for by the log file, and (2) evaluate this method and determine its accuracy and reproducibility.

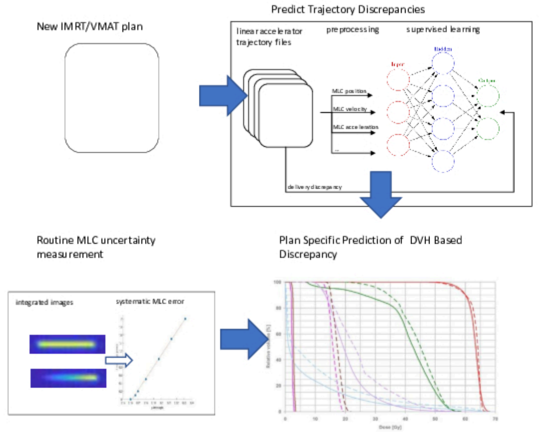

Figure 1: Proposed instantaneous (after treatment planning), measurement-based pre-treatment QA procedure with DVH based analysis.

METHOD

1. MLC trajectory & QA Test Design

- In each IMRT field, all leaves of a bank (A or B) simultaneously move across a 3-cm gap at a constant speed (either 0.1 cm/s or 2.5 cm/s).
- The leaf openings are interspersed throughout the field to minimize effect of scatter (Figure 2a).
- A static open field (Figure 2b) and two closed fields (Figures 2c and 2d) are also included in the plan for normalization.
- In an initial set of calibration images, intentional leaf lags are also included ranging from 0.1 mm to 2.0 mm.

2. QA Analysis:

- The image intensity of each IMRT field is first normalized to the image intensity of the static open field:

$$\frac{I - I_{closed}}{I_{open} - I_{closed}} \quad \text{(eqn. 1)}$$

- Next, the average intensity in the center of the field for each leaf opening is determined using a linear fit to the normalized curves.
- Measured leaf gaps from trajectory files are accounted for using the following equations:

$$\text{Leaf lag measured in the log file} = \text{planned MLC positions} - \text{actual MLC positions} \quad \text{(eqn. 2)}$$

$$\text{Actual leaf lag} = \text{planned leaf lag} + \text{average leaf lag from the trajectory log files} \quad \text{(eqn. 3)}$$

- In order to determine the systematic leaf lag for each leaf, the calibration images are used to establish the relationship between image intensity and actual leaf lag (Figure 3d).

3. Accuracy and reproducibility of EPID based measurement:

- Plans are delivered three times to quantify the minimum detectable MLC discrepancy (Figure 4a).
- Number of deliveries needed to obtain a resolution of 0.05 mm is determined using the following equation:

$$\text{number of deliveries} = \left(\frac{\text{standard deviation}}{\text{resolution}}\right)^2 \quad \text{(eqn. 4)}$$

- We do this verification test to verify that the standard deviation of the MLC positions are within the tolerance and that the number of deliveries is small enough to be performed during an actual MLC QA.

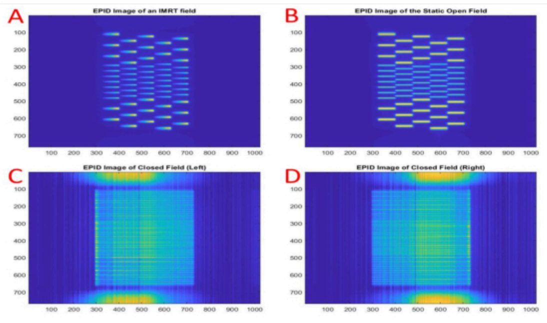

Figure 2: EPID images of a) an IMRT field in which all leaves of bank B move across a 3-cm gap simultaneously at a constant speed of 0.1 cm/s; b) a static open field; c) and d) closed field with leaves parked at each side

RESULTS

- Intensity profiles for each moving leaf with and without intentional lag (Figure 3b) shows a linear relationship between the image intensity and distance of leaf travel.
- Normalized curves for each moving leaf (Figure 3c) show that the larger the lagging values, the greater the total intensity at any point in the leaf opening.
  - Linear fit of the normalized curves: R^2 of 1.000 for both leaf speeds.
- Linear relationship between the actual lagging value of each leaf and the average intensity in the center of the leaf opening (Figure 3d).

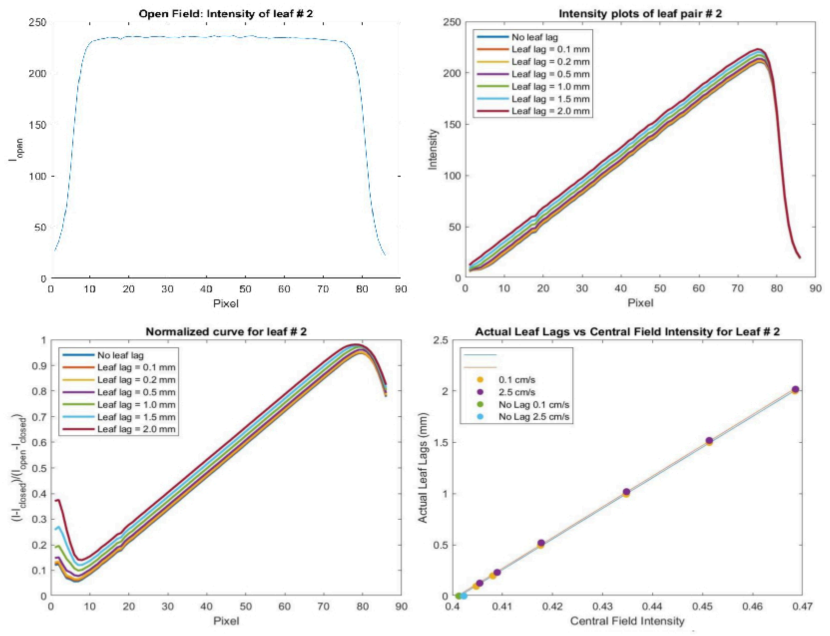

Figure 3: Intensity profiles for a) the open field and b) the IMRT field with the same speed and leaf opening; c) results after normalizing each IMRT field to the open field; and d) the linear relationship between actual leaf lags and central field intensity for leaf # 2 of bank B.

Table 1: Statistical results for 0.1 cm/s and 2.5 cm/s plans.

	0.1 cm/s	2.5 cm/s
Average Stdev of Central Field Intensity (I)	0.0004	0.0006
Slope (mm/I)	30.07	29.47
Average Stdev of MLC position (mm)	0.013	0.018
Precision (mm)	0.05	0.05
Average Required N for all leaves	0.087	0.16

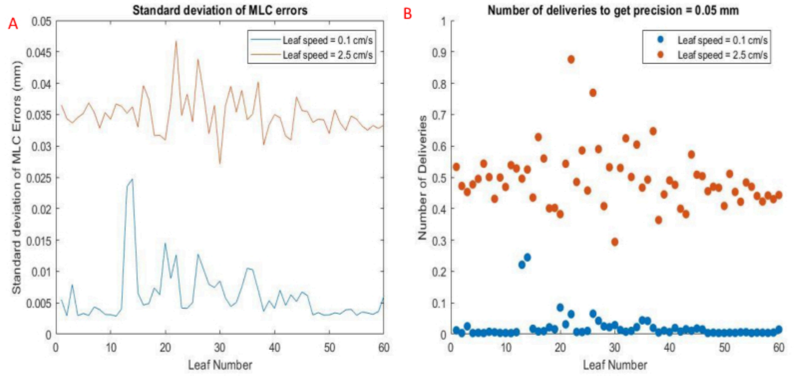

Figure 4: a) Standard deviations of MLC discrepancies for each leaf; b) Number of deliveries to get precision of 0.05 mm.

- As shown in Table 1 (or Figure 4b), the standard deviation of measured systematic MLC errors is less than 0.1 mm, and we only need to deliver each plan once to obtain a resolution of 0.05 mm.

CONCLUSIONS

- In conclusion, we have developed a method to measure MLC positional discrepancies not accounted for in the trajectory file during a dynamic MLC motion using a simple QA plan with integrated EPID images.
- Per Table 1 a single delivery can provide the sufficient precision to detect systematic MLC discrepancies of 0.05mm.
- Further development of the model will include verifying our method by comparing with other methods such as picket fence, MPC, and other EPID based MLC QA.
- Incorporating the results from the EPID based MLC QA into the trajectory file based pre-treatment QA prediction model will enable instantaneous, patient specific, measurement based pre-treatment QA.

REFERENCES

[1] Nelms, Benjamin E., Heming Zhen, and Wolfgang A. Tomé. "Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors." *Medical physics* 38.2 (2011): 1037-1044.

[2] Acharya, Sahaja, et al. "Online magnetic resonance image guided adaptive radiation therapy: first clinical applications." *International Journal of Radiation Oncology* Biology* Physics* 94.2 (2016): 394-403.

[3] Men, Chunhua, Xun Jia, and Steve B. Jiang. "GPU-based ultra-fast direct aperture optimization for online adaptive radiation therapy." *Physics in Medicine & Biology* 55.15 (2010): 4309.

CONTACT INFORMATION

For more information, please contact the author at:
Email: Lam.lay@duke.edu