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From Fluence to Dose: Real-Time Adaptive MLC Tracking using Dose Optimization

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SUMMARY

- Dose Optimization accounts for 3D dose errors in real-time during radiotherapy delivery with MLC tracking
- Dose Optimization outperforms previous real-time fluence optimization and without optimization
- Real-time performance is achieved, allowing use during treatment
- Can be adapted for multi-target applications OAR sparing

MOTIVATION

- Intrafraction motion causes a reduction in dose delivered to the target, while increasing dose to healthy tissue
- Current clinical workflow accounts for anatomical motion in the following ways:
  - Replanning pre-treatment for interfraction motion
  - Pausing mid-treatment through gating or breath-hold
- By observing motion during treatment, one can actively adapt the treatment to minimize intrafraction motion errors[1]
- The multi-leaf collimator is ideally equipped to account for this motion
  - Widely available
  - Can adapt for full 6 DOF motion
- The current MLC optimization is based on fluence[2], with a number of limitations:
  - Optimization not representative of underlying 3D patient anatomy
  - Error accumulation in 2D space provides modest improvements[3]
- We seek to improve current methodology by extending to 3D and accumulating dose, thereby better informing the MLC aperture position

METHOD

- MLC tracking requires observation of target motion and aperture optimization.
- During treatment, motion can be inferred through several different methods:
  e.g. implanted markers[4] or markerless tracking[5] through CT or 4D MRI imaging

REAL-TIME FLUENCE OPTIMIZATION

- Current aperture optimization of the MLC aperture is based on fluence[2]:
  - The shape of the planned aperture is shifted in with the target motion
  - Under/overdose minimization on the fluence is performed
- This has been clinically implemented, successfully reducing motion error[6]

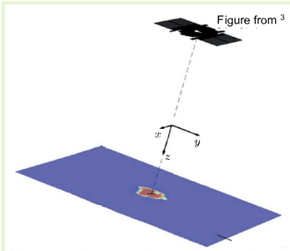
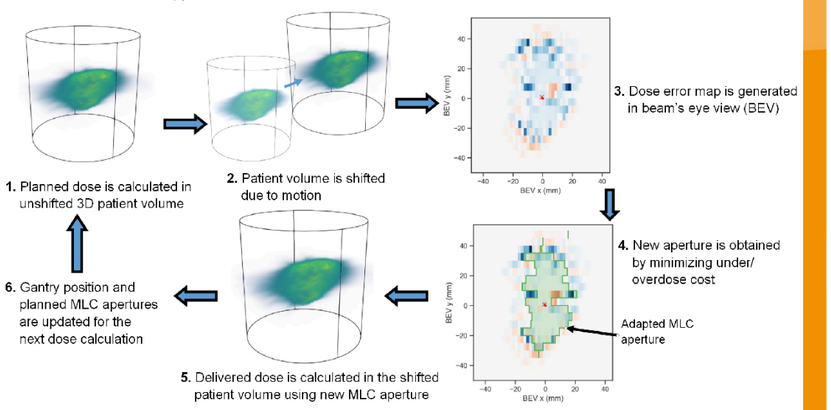


Fig. 1. In fluence optimization, the MLC is adapted to the 2D fluence provided by the linear accelerator

REAL-TIME DOSE OPTIMIZATION

- Dose Optimization accounts for the moving patient anatomy by accumulating dose in silico during treatment
- Requires calculation of dose as treatment progresses in real time (e.g.[7,8])
- This methodology is as follows:



- For real-time performance, dose is accumulated using a line-of-sight dose calculation
- It accumulates and accounts for errors due to finite leaf widths and leaf velocities
- Adapts for the evolution of dose errors in the beam's eye view due to motion and gantry rotation
- Can be used to a wide array of radiotherapy treatments: VMAT, IMRT, etc.

RESULTS

- Method applied to a prostate cancer VMAT treatment dataset with observed intrafraction motion (14 fractions).
- Here, we briefly look at a fraction in this dataset.
- Fig 3. shows the comparison between fluence and dose optimization.
  - With dose opt. (1), the underlying cost function shows spatial variation due to accumulated errors, blue indicating regions of underdose, red overdose.
  - Fluence opt. (2) has a more binary representation and does not consider accumulated errors.
- Fig. 2 shows a 2D slice of the 3D dose distribution. Dose optimization reports lower dose errors compared to the other two.
- During the treatment, fig. 4 shows that the dose error increases as treatment progresses, but dose optimization minimizes the error, keeping the dose error lower than other optimization methods

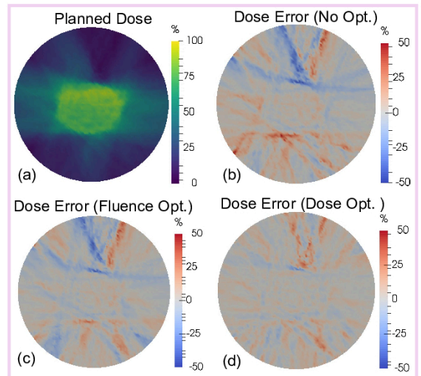


Fig. 2. Axial slices of the patient volume, showing (a) normalized planned dose distribution, dose error (% of planned dose) with no optimization (b) and fluence optimization (c) and dose optimization (d).

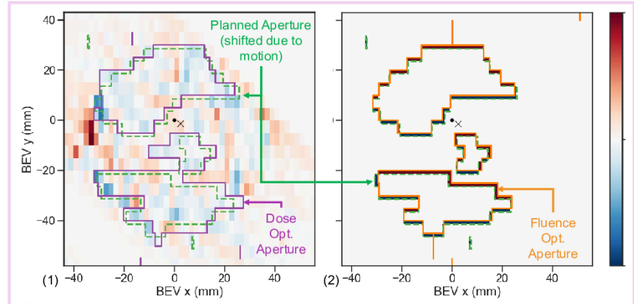


Fig 3. Aperture comparison between fluence and dose optimization, showing the underlying cost function. Blue indicates underdose, red overdose

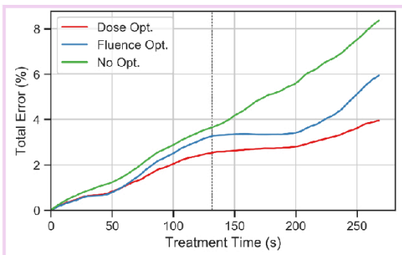


Fig. 4. Dose error during treatment for each optimization method.

OVERALL RESULTS

- Overall, dose optimization outperforms no tracking and fluence for all fractions
- Fig 5.2 shows the overall statistics, with dose optimization showing a lower average and less spread

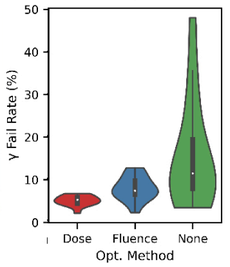


Fig. 5. Violin plots of γ failure rates (2%/2mm). Dose Optimization performs best, with a lower mean (white dot) and smaller spread of γ failure rates

FUTURE WORK

- This work shows that MLC adaptation based on accumulated does outperforms previous real-time fluence based optimization
- Can be extended to multitarget/OAR sparing applications readily
  - Tissue voxels can be weighted to target/avoid certain regions
- On the path to real-time adaptive re-planning
  - With 3D dose accumulation, optimization can be performed based on future dose
  - Improves on conformance to planned dose
  - Better avoid OAR by dosing at correct angles

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