Real-time adaptive dose scaling during MLC-tracking on the Elekta Unity MR-Linac

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Introduction

- Intra-fractional tumour motion is a major source of uncertainty in EBRT.
- Motion can be visualized in real-time using 2D Cine MRI.
- MLC-tracking, i.e. continuously adjusting leafs and diaphragms, can mitigate such geometric target displacements.
- MLC-tracking does however not account for the spatially varying FFF beam profile.
- We demonstrate how MLC-tracking can be combined with real-time adaptive dose scaling to account for the FFF beam profile.

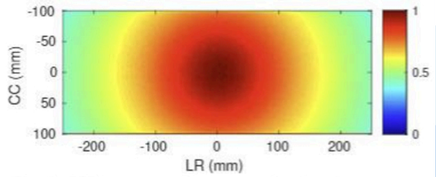

Fig. 1: FFF beam profile, normalized at iso-center

Methods

- 1.5T Unity MR-Linac[2] with MLC-tracking firmware[1]
- Quasar MRI[4D] motion phantom[3]
  - Film insert with a 30mm target
  - 100mm laterally off-iso-center
  - Cos[4] (T=5s, Ampl = 15mm) trajectory
  - Cranial table offsets of 25mm/50mm to simulate large shifts.
- Liver SBRT plan (3x20Gy, 15-beam)

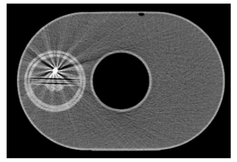

Fig. 2a: CT slice through showing the body oval, target and film insert

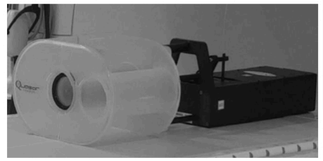

Fig. 2b: motion phantom

Imaging and Tracking

- 4Hz 2D Cine-MRI
- Position calculated using template matching
- Linear Ridge regression prediction for 240-490ms system latency.
- MLC aperture adapted every 80ms

Dose scaling

- Baseline position calculated from average position of last two respiratory cycles.
- Projected into a relative baseline shift in the FFF profile.
- Monitor units of subsequent segments scaled accordingly.

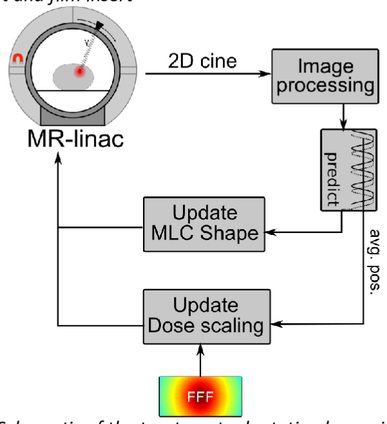

Fig. 3: Schematic of the treatment adaptation loop with MLC-tracking based on the predicted position and Dose scaling based on the average position.

Results

- For target shifts >20mm, the dose diff. is >1% (Fig. 4).
- Gamma analysis (2%/2mm/2Gy thresh.) w.r.t. static delivery.

Gamma pass-rate	No Scaling	Scaling
0mm cc baseline shift	99%	
25mm cc baseline shift	89.9%	99.9%
50mm cc baseline shift	60%	90%

Table 1: gamma pass-rate values for varying baseline offsets with and without adaptive dose scaling

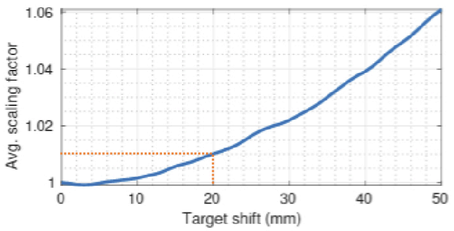

Fig. 4: Dose scaling factor as a function of target shift.

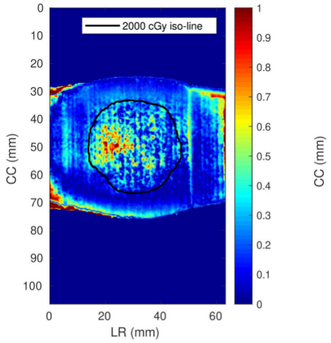

Fig. 5a: Gamma maps for 0mm cc shift

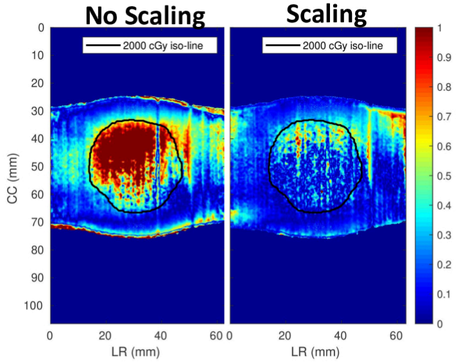

Fig. 5b: Gamma maps for 25mm cc shift

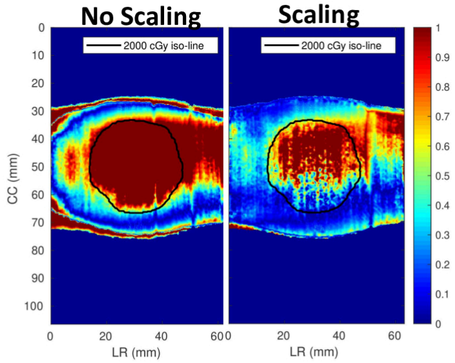

Fig. 5c: Gamma maps for 50mm cc shift

Conclusion and Discussion

- MLC-tracking results in highly conformal dose distributions, compensating for respiratory motion.
- The FFF beam profile can be accounted for by adapting the target dose per segment on-the-fly during delivery.
- For target shifts >20mm, the FFF profile needs to be accounted for.
- For target shift of 25mm, adaptive dose scaling significantly improved the Gamma pass-rate.
- For unrealistic large targets shifts of 50mm, the proposed dose scaling method is insufficient.

[1]Glitzner et al. doi: 10.1088/1361-6560/ab2667
[2]Elekta AB [3]Modus Medical Devices

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