Experimental validation of delivery of robust mixed-beam radiotherapy plans

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INTRODUCTION

Mixed-beam radiotherapy (MBRT) uses intensity modulated electron and photon beams collimated by the photon MLC. Previous studies[1] have shown that MBRT plan give superior plan quality compared to photons-only VMAT and IMRT in the treatment of tumours with a superficial component.

Renaud *et al.*[2] previously showed that conventional PTV margins may not be effective at compensating for setup errors in MBRT. They implemented a robust optimization approach for MBRT using column generation, however, their method did not generate deliverable plans.

AIMS

- Implement a robust optimization process within a previously developed hybrid direct aperture optimization (DAO) framework for generating deliverable MBRT plans.
- Experimentally validate delivery of robust MBRT plans.
- Compare robust MBRT plans with conventional PTV-based MBRT plans

METHODS

- Implemented robust optimization process within our hybrid DAO framework (Fig 1). Robust optimization is implemented for simulated annealing and gradient descent optimization by minimizing the expectation value of the objective function for all considered error scenarios.
- Generate a robust MBRT plan considering 5 mm systematic translational setup errors for an artificial brain tumour case created on an Alderson head phantom (Fig 2).
- Delivered plan using the Developer mode on a standard TrueBeam linac. Planar dose distributions measured inside the Alderson head phantom with EBT3 film. Plan was delivered with and without 5 mm isocenter shifts.
- Compared robust MBRT plan with an MBRT plan generated using a conventional PTV with 5 mm CTV-PTV margin. Optimization objectives were identical to robust plan, except that the target volume was the PTV instead of the CTV.

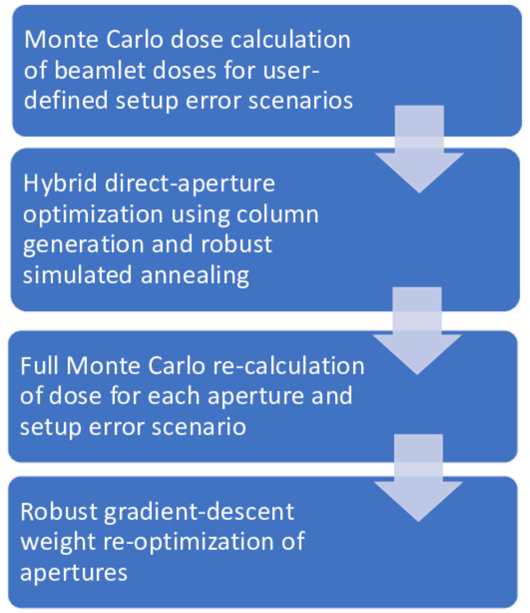

Fig 1: Robust hybrid DAO process for MBRT

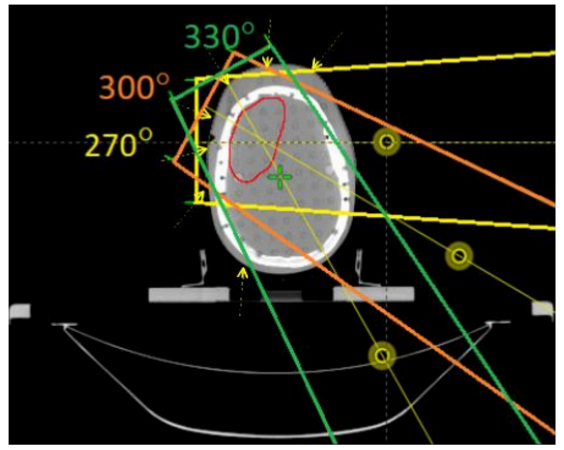

Fig 2. Axial CT slice of Alderson head phantom showing CTV and electron beam directions. Six electron beams, one for each available energy (6, 9, 12, 15, 18, 22 MeV) are defined for each direction. Electron beam SSD ranged from 67.9 cm to 82.3 cm. Dashed arrows indicate the directions of the seven additional 6MV isocentric photon beams.

CONCLUSIONS

This work demonstrates, for the first time, experimental validation of the delivery of robust MBRT plans. Robust optimization is a promising alternative to traditional PTV margins to account for setup uncertainties in MBRT.

ACKNOWLEDGEMENTS

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REFERENCES

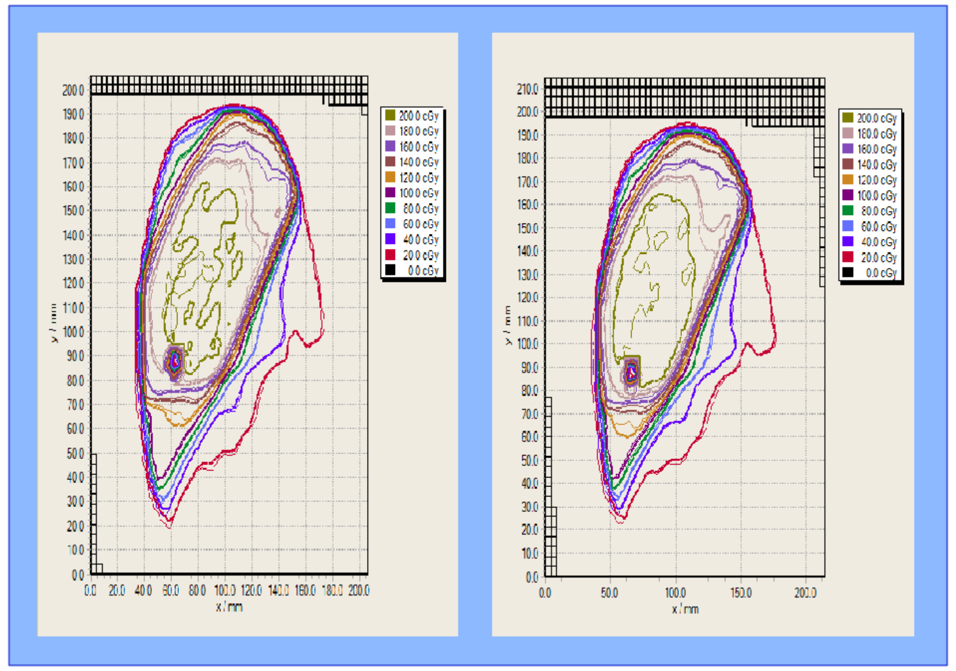
1 **Mueller S et al.** Simultaneous optimization of photons and electrons for mixed beam radiotherapy. *Physics in Medicine & Biology 2017; 62(14): 5840.*

2 **Renaud MA et al**. Robust mixed electron-photon radiation therapy optimization. *Medical Physics 2019; 46(3): 1384-96.*

RESULTS

Key results:

- Agreement between measurements and calculations is better than 97.7% when comparing total dose and dose due to photon apertures only (Fig 3 and Table 1)
- 96.9% gamma passing rate for dose due to electron apertures (Table 1)
- Robust and PTV-based MBRT plans had similar target coverage (CTV D95%) (Fig 4)
- The robust MBRT plan achieved better OAR sparing compared to the PTV-based MBRT plan (Fig 4). On average, the D2% was 33% lower for the robust plan.

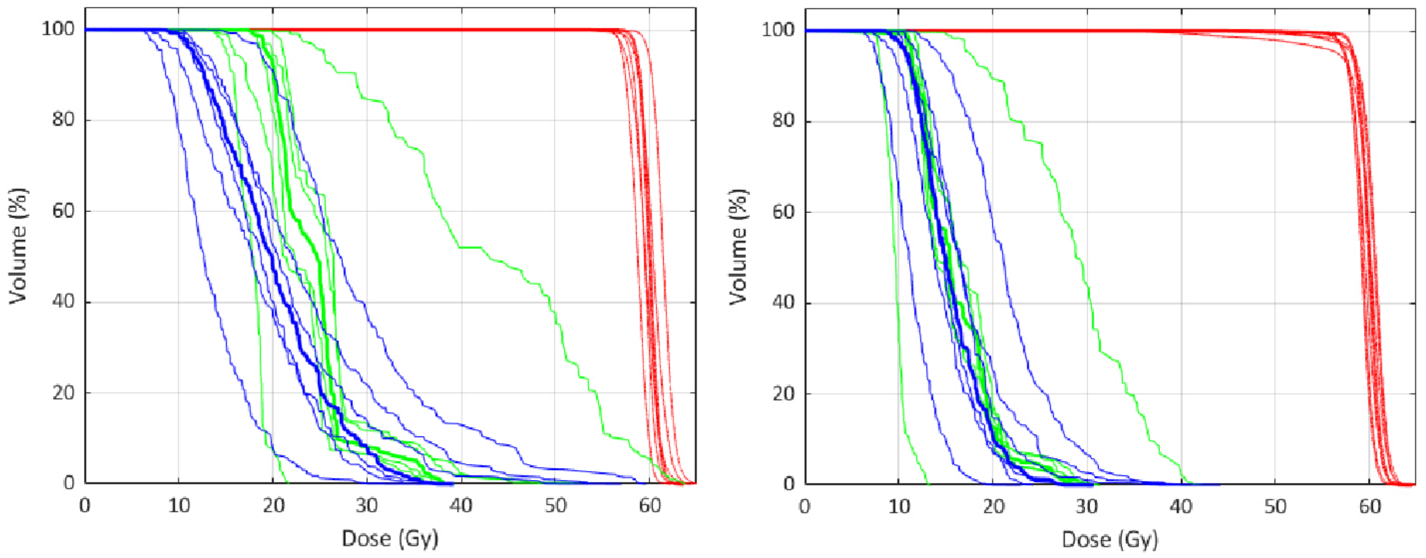


(a) no shift (b) with 5 mm lateral shift

Fig 3. Comparison of measured (thin lines) and calculated (thick lines) isodose distributions for total plan dose delivery in measurement slice 2 with and without isocenter shift.

Measurement slice (from top of head)	Dose	Gamma passing rate (3%/2mm, 10% threshold)		
		No shift	With shift	
1	Total	98.1%	inferior	98.7%
1	Photon	98.7%	inferior	98.8%
1	Electron	96.9%	inferior	96.9%
2	Total	97.7%	lateral	97.7%

Table 1. 2D Gamma passing rate for comparison of film measurements and dose calculation in measurement planes of Alderson head phantom.



(a) PTV plan (b) Robust plan

Fig 4. DVHs for CTV (red), right optic nerve (green) and chiasm (blue) evaluated for the plan (thick line) plus 6 setup error scenarios (thin lines) consisting of 5 mm shifts along each principal axis (SI,LR,AP).

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