A spatial analysis of biological dose distributions in the brainstem and its substructures in proton therapy of paediatric brain tumours

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Introduction

- In proton therapy of paediatric posterior fossa tumours, the brainstem is considered to be a particularly radiosensitive organ.
- Different models for the relative biological effectiveness (RBE) of protons will predict different biological dose due to varying linear energy transfer (LET), which may further influence the dose to the brainstem [1].
- The objective of this study was to investigate the magnitude and spatial overlap of biological dose distributions derived from established RBE models, focusing on the brainstem and its substructures.

Material and Methods

- The brainstem, brainstem core (brainstem cropped by 3 mm) and surface, medulla oblongata, pons, and midbrain were delineated on CT/MR images for a five-year-old male with a posterior fossa tumour (Figure 1).
- An intensity-modulated proton therapy plan prescribing 54 Gy(RBE) to the PTV was generated in Varian Eclipse. The plan was optimised using RBE = 1.1 and had two lateral anterior fields in addition to a vertex treatment field (Figure 2).
- The treatment plan was further translated to the FLUKA Monte Carlo code for recalculation and LET extraction.
- Biological doses to the brainstem and substructures were compared using ($^{\alpha}/_{\beta} = 2.1$ [2]):
  - $RBE_{1.1}$ dose
  - LET-weighted dose (weighted purely on LET) [3]
  - Carabe model [4]
  - McNamara model [5]
  - Wedenberg model [6]
- Overlap of dose distributions between the RBE models were compared for multiple iso-biological dose levels.

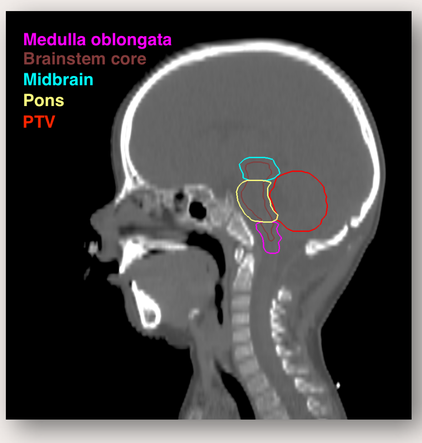

Figure 1: CT image of the patient with relevant volumes delineated (sagittal view). Brainstem consists of midbrain, pons and medulla oblongata. Brainstem core is the brainstem cropped by 3 mm. Brainstem surface is brainstem with core subtracted.

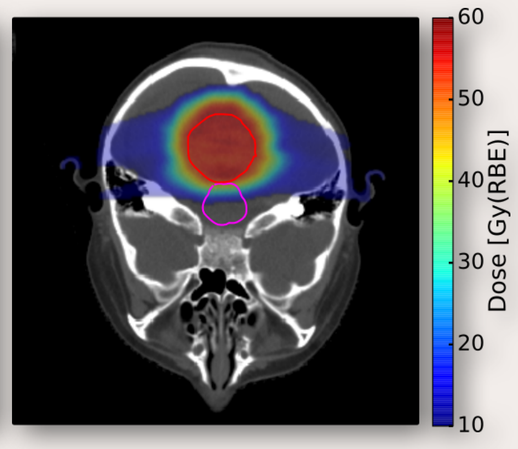

Figure 2: Distribution of $RBE_{1.1}$ dose (axial view). Voxels receiving doses below 10 Gy(RBE) are transparent. Brainstem delineated in magenta.

Conclusions

- Using RBE models introduced increased biological doses to the brainstem and resulted in larger isodose volumes.
- Although the RBE models calculated different magnitude of biological doses, they spatially coincided in regions of increased dose.
- The regions of increased LET-weighted dose also coincided with the increased biological doses from the RBE models, hence simpler biological dose optimisation strategies based on LET may be an option.

References

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[4] A. Carabe et al., Phys Med Biol 57, 1159. (2012)
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Results

- All models predicted higher biological dose to all structures compared to using $RBE_{1.1}$ (Table 1 and Figure 3).
- The Wedenberg model predicted the highest biological dose for all structures while the LET-weighted dose reported the lowest values (excluding $RBE_{1.1}$ dose) (Table 1 and Figure 3). The overall highest doses occurred in the medulla oblongata, mainly attributed to elevated LET.
- Using the Wedenberg dose as a reference, the spatial distributions of biological dose in the brainstem calculated by the models fully overlapped for all substructures (Table 2 and Figure 4). The 30 Gy(RBE) isodose volume from Wedenberg was 33 % larger compared to the corresponding $RBE_{1.1}$ isodose volume within the brainstem.

Table 1: Median dose in Gy(RBE) for the relevant structures.

Median dose [Gy(RBE)]	**Structure**					
Model	Brainstem	Brainstem core	Brainstem surface	Midbrain	Pons	Medulla oblongata
Wedenberg	14.0	16.7	11.3	8.6	16.6	18.5
McNamara	13.2	15.8	10.6	8.2	15.8	17.2
Carabe	13.0	15.6	10.4	7.9	15.5	17.5
LET-weighted dose	10.1	12.4	7.8	6.3	12.4	12.2
$RBE_{1.1}$ dose	9.5	11.8	7.3	6.2	11.8	10.7

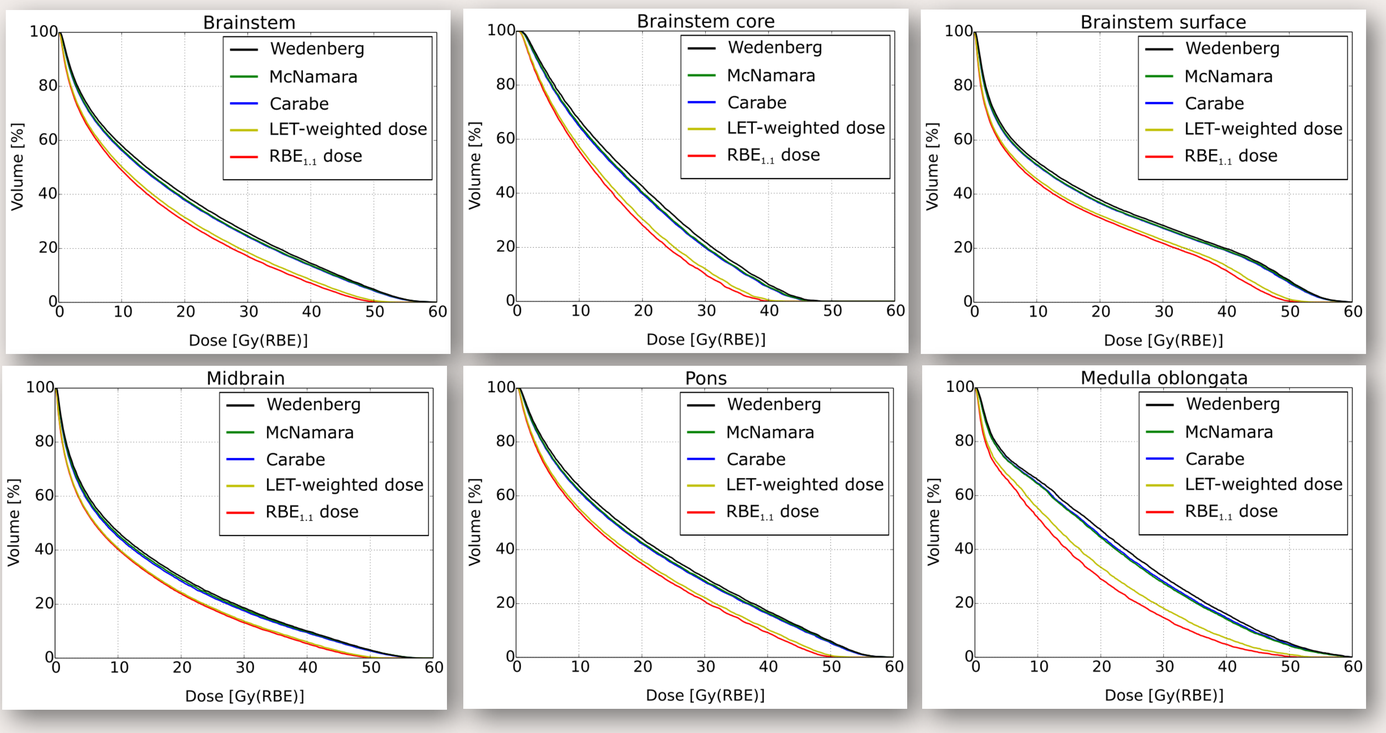

Figure 3: Dose volume histograms for the entire brainstem, brainstem core and surface, midbrain, pons and medulla oblongata.

Table 2: Volume sizes in % and cc of isodoses at 20 and 30 Gy(RBE).
Percentage values represented using the Wedenberg predicted dose as reference (100 %).

Volume size [% (cc)]	**Structure (total volume)**											
	Brainstem (20.5 cc)		Brainstem core (8.2 cc)		Brainstem surface (12.4 cc)		Midbrain (7.2 cc)		Pons (9.9 cc)		Medulla oblongata (3.4 cc)	
Model	20 Gy(RBE)	30 Gy(RBE)	20 Gy(RBE)	30 Gy(RBE)	20 Gy(RBE)	30 Gy(RBE)	20 Gy(RBE)	30 Gy(RBE)	20 Gy(RBE)	30 Gy(RBE)	20 Gy(RBE)	30 Gy(RBE)
Wedenberg	100 (8.2)	100 (5.4)	100 (3.5)	100 (1.8)	100 (4.7)	100 (3.5)	100 (1.7)	100 (1.0)	100 (3.9)	100 (2.6)	100 (1.6)	100 (1.0)
McNamara	96 (7.9)	95 (5.1)	96 (3.4)	92 (1.7)	96 (4.5)	97 (3.4)	99 (1.6)	98 (1.0)	96 (3.8)	95 (2.5)	96 (1.5)	93 (1.0)
Carabe	95 (7.8)	94 (5.0)	95 (3.3)	91 (1.7)	96 (4.5)	97 (3.4)	95 (1.6)	97 (1.0)	96 (3.7)	93 (2.4)	98 (1.6)	95 (1.0)
LET-weighted dose	79 (6.5)	71 (3.8)	72 (2.5)	54 (1.0)	84 (3.9)	80 (2.8)	79 (1.3)	71 (0.7)	82 (3.2)	74 (1.9)	70 (1.1)	60 (0.6)
$RBE_{1.1}$ dose	75 (6.1)	67 (3.6)	67 (2.3)	48 (0.9)	82 (3.8)	77 (2.7)	78 (1.3)	70 (0.7)	79 (3.1)	72 (1.9)	62 (1.0)	50 (0.5)

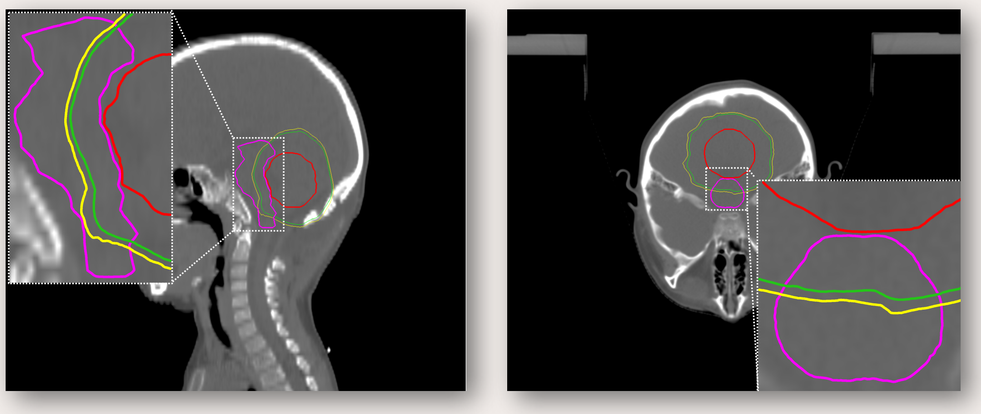

Figure 4: Sagittal and axial view of the 20 Gy(RBE) isodose curves from Wedenberg (yellow) and $RBE_{1.1}$ (green). The Wedenberg isodose volume was 25 % larger than the $RBE_{1.1}$ volume within the brainstem. The isodose curves for the other models were located in-between. Outlined in magenta is the brainstem while the PTV is delineated in red.

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