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JOINT AAPM | COMP MEETING

Integrated Physical and Radiobiological Evaluation of Radiotherapy for Brain Cancer Using MATLAB-Based Outcome Modeling

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ABSTRACT

Purpose: Accurate radiotherapy for brain tumors requires highly conformal dose delivery to maximize tumor control while limiting damage to adjacent critical neural structures. Although intensity-modulated radiotherapy (IMRT) is routinely employed, plan evaluation is commonly based only on physical dose parameters. This study aimed to establish and apply an integrated assessment approach combining advanced physical quality indices with radiobiological outcome modeling to enhance the clinical relevance of IMRT plan evaluation.

Methods: Ten clinically approved IMRT brain tumor plans were created using the Eclipse Treatment Planning System (Version 13.6) with nine optimized beam arrangements and a prescription dose of 60 Gy delivered in 30 fractions. Plan quality was assessed using multiple physical metrics derived from RTOG, SALT, Lomax and Scheib, and van't Riet models, including conformity, homogeneity, target coverage, and healthy tissue sparing indices. Radiobiological evaluation was performed using a custom-developed MATLAB tool that extracted cumulative dose–volume histogram (DVH) data to calculate Equivalent Uniform Dose (EUD)-based Tumor Control Probability (TCP) and Normal Tissue Complication Probability (NTCP).

Results: All IMRT plans demonstrated clinically acceptable target coverage and dose homogeneity consistent with established recommendations. Conformity indices indicated highly precise dose shaping around target volumes. Slight reductions in quality metrics were observed for targets located near the skin, attributable to anatomical constraints. SALT-based parameters confirmed effective sparing of normal tissues in most cases. Radiobiological modeling revealed high predicted tumor control probabilities and low complication risks for organs at risk, supporting the biological robustness of the physically optimized plans.

Conclusion: The proposed framework enables comprehensive evaluation of IMRT plans by integrating physical and radiobiological metrics. The results confirm that high geometric precision in IMRT for brain tumors can be accompanied by favorable predicted biological outcomes. Incorporating TCP and NTCP modeling into routine plan assessment may improve clinical decision-making and facilitate future treatment optimization.

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INTRODUCTION

Accurate radiotherapy for brain tumors requires highly conformal dose delivery to maximize TCP and minimize to NTCP. Although intensity-modulated radiotherapy (IMRT) is routinely employed, plan evaluation is commonly based only on physical dose parameters. This study aimed to establish and apply an integrated assessment approach combining advanced physical quality indices with radiobiological outcome modeling to enhance the clinical relevance of IMRT plan evaluation.

METHODS AND MATERIALS

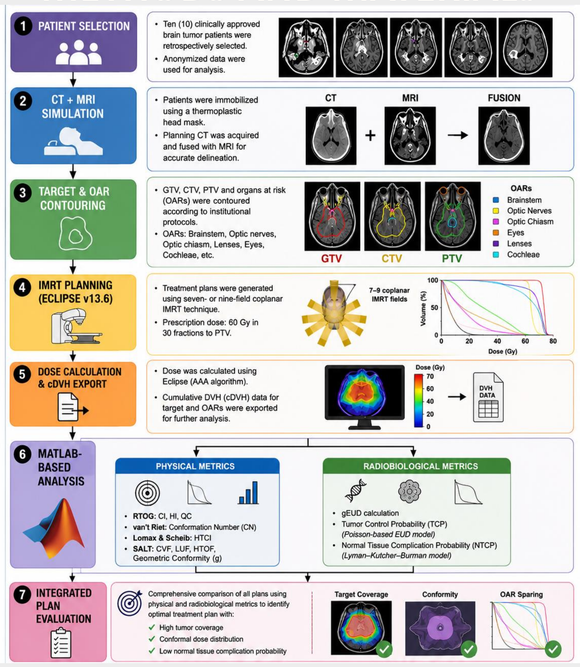


Figure 1: Treatment Planning for Brain

		Parameters	Equations	Limit
Physical Parameters	RTOG	CI	$\frac{I_{max}}{RI}$	1 – 2
		HI	$\frac{TV_{RI}}{TV}$	≥ 1 or = 2
		QC	$\frac{I_{min}}{RI}$	≥ 90%
	SALT	CVF	$\frac{LV_{RI}}{LV} = \frac{TV_{RI}}{TV}$	≃ 1
		LUF	$\frac{LV_{x\%}}{LV}$	≃ 0
		HTOF	$\frac{\text{Dose received by healthy tissue}}{\text{Dose received by target tissue}}$	≃ 0
		g	LUF + HTOF	≃ 0
	Van't Riet et al.	CN	$\frac{CTV_{RI}^2}{TV \times V_{RI}}$	0 to 1
	Lomax & Scheib	HTCI	$\frac{V_{50} - TV}{V_{50}}$	≃ 1
Biological Parameters	TCP	EUD based model	$TCP = \frac{1}{1 + \left(\frac{TCD_{50}}{EUD}\right)^{4\gamma_{50}}}$	≃ 1
		Poisson statistics	$TCP = \left(\frac{1}{2}\right)^{D\,V_i} \exp\left[\frac{2}{m\,2}\gamma_{50}\left(1 - \frac{D_i}{D_{50}}\right)\right]$	≃ 1
	NTCP	EUD based model	$NTCP = \frac{1}{1 + \left(\frac{TD_{50}}{EUD}\right)^{4\gamma_{50}}}$	≃ 0
		LKB model	$NTCP = \frac{1}{1 + \left(\frac{D}{TD_{50}}\right)^{m}}$	≃ 0

CI: Conformity Index; HI: Homogeneity Index; QC: Quality of Coverage; CN: Conformation Number; CVF: Coverage Factor; LUF: Lesion Underdosage Factor; HTOF: Healthy Tissue Overdosage Factor; g: Geometric Conformity; HTCI: Healthy Tissue Conformity Index; TCP: Tumor Control Probability; NTCP: Normal Tissue Complication Probability.

Table 2: *Physical and biological evaluation parameters*

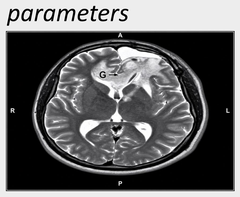


Figure 3. Brain.

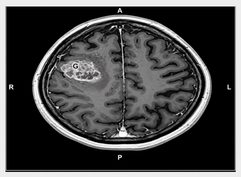


Figure 4. Brain.

RESULTS

All IMRT plans demonstrated clinically acceptable target coverage and dose homogeneity consistent with established recommendations. Conformity indices indicated highly precise dose shaping around target volumes. Slight reductions in quality metrics were observed for targets located near the skin, attributable to anatomical constraints. SALT-based parameters confirmed effective sparing of normal tissues in most cases. Radiobiological modeling revealed high predicted tumor control probabilities and low complication risks for organs at risk, supporting the biological robustness of the physically optimized plans.

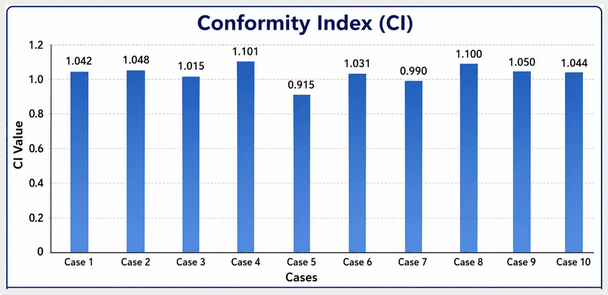


Figure 5: conformity index

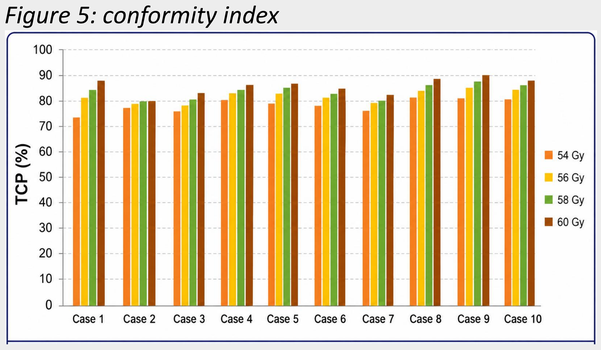


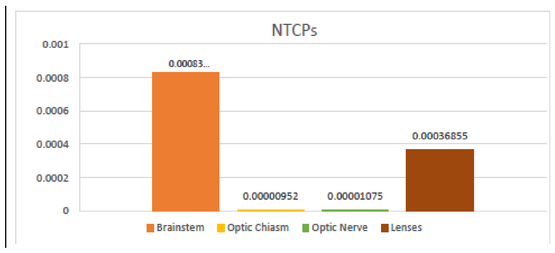
Figure 6: TPC

Case No.	PTV		Brainstem		Optic Chiasm		Optic Nerve		Lenses	
	TCP (≥ 1%)	EUD (Gy)	NTCP: ≥ 0 (%)	EUD (Gy)	NTCP: ≥ 0 (%)	EUD (Gy)	NTCP: ≥ 0 (%)	EUD (Gy)	NTCP: ≥ 0 (%)	EUD (Gy)
01	88	64.41	0.00003	15.54	0.000003	15.54	0.00000012	14.66	0.000001	0.21
02	80.39	61.75	0.00005	16.18	0.0000093	16.87	0.00000026	12.54	0.002	1.22
03	83.32	61.8	0.0001	21.05	0.0000023	15.01	0	9.27	0.0005	0.915
04	85.58	62.93	0.0002	21.93	0.0000012	14.23	0.00000093	16.87	0.00000015	0.22
05	86.39	63.4	0.00002	18.24	0.0000052	16	0.000017	17.78	0.00012	0.6
06	84.48	62.34	0.00001	14.23	0.0000062	13.45	0.0000048	15.98	0.0004	0.45
07	81.73	61.01	0	7.48	0.00002	18.42	0.0000029	15.32	0.00005	0.47
08	88.44	64.71	0.005	29.15	0.000016	17.59	0.000043	19.16	0.000006	0.29
09	89.91	64.8	0	8.54	0.000012	17.2	0.000022	18.24	0.000007	0.3
10	87.55	64.11	0.002	26.54	0.00002	18	0.0000067	16.42	0.0005	0.85

Figure 7. Biological Value

DISCUSSION

The evaluated IMRT plans achieved excellent target conformity, dose homogeneity, and clinically acceptable organ-at-risk sparing. Physical dosimetric indices (RTOG, SALT, Conformation Number, and Healthy Tissue Conformity Index) consistently demonstrated high-quality treatment plans. MATLAB-based radiobiological modeling further showed high EUD-based Tumor Control Probability (TCP) with very low Normal Tissue Complication Probability (NTCP) for critical structures, indicating favorable therapeutic outcomes. The automated cDVH analysis improved the efficiency and reproducibility of plan evaluation. These findings demonstrate that integrating physical dosimetry with radiobiological outcome modeling provides a more comprehensive and clinically meaningful assessment than conventional dosimetric evaluation alone.



CONCLUSSIONS

This study demonstrated that IMRT achieved excellent target coverage, conformity, and dose homogeneity while effectively sparing surrounding organs at risk. Physical dosimetric indices (RTOG, SALT, Conformation Number, and Healthy Tissue Conformity Index) confirmed consistent plan quality across all evaluated cases. MATLAB-based radiobiological modeling predicted high Tumor Control Probability (TCP) and low Normal Tissue Complication Probability (NTCP), indicating favorable therapeutic outcomes. Integrating physical dosimetry with radiobiological outcome modeling provides a more comprehensive and clinically relevant framework for treatment plan evaluation. The proposed MATLAB-based approach offers an efficient, reproducible tool for biologically informed optimization of brain IMRT treatment plans.

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