

# Image Guided HDR Brachytherapy Planning: The Implication of Incorporating Biological Effects into Paradigms Based on Physical Dose

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**Purpose:** To develop an algorithm to optimize high dose rate (HDR) brachytherapy plans using both physical dose and biological effects-based objectives

## Why biology effects-based optimization:

- Treatment effectiveness and tissue complications are measured biologically
- Physical dose-based planning does not take biological effects into account
- Multi-modality images provide anatomical/metabolic data for tumor and critical organs
- Incorporate these data in the planning process may result in better treatment

## Method and Materials:

- Adaptive simulated annealing (ASA) algorithm is used to determine dwell times at various dwell positions
- Plans are evaluated using following indices  
Coverage index (CI): target fraction receiving at least prescription dose  
Homogeneity index (HI): target fraction receiving 100-150% of prescription dose  
Overdose index (OI): target fraction exceeding 200% of prescription dose  
Tumor control probability (TCP)  
Normal tissue complication probability (NTCP)  
Equivalent uniform dose (EUD)

## Objective functions used:

Physical dose-based

$$OF = \sum_j (D_j - D_j^p)^2$$

where  $D_j^p$  is prescribed dose at volume element  $j$

## EUD-based

$$OF = 1 - \prod_j f_j$$

where  $f_j$  are scoring functions for tumor and organ at risk defined below

$$f_T = \frac{1}{1 + \left(\frac{EUD}{EUD_0}\right)^n} \quad f_{OAR} = \frac{1}{1 + \left(\frac{EUD_0}{EUD}\right)^n}$$

## TCP/NTCP-based

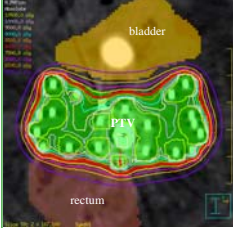
$$OF = N(1 - TCP) + \sum_j^N NTCP_j + OI$$

where N is the number of organs at risk

- The planning was applied to a gynecological cancer case. PTV was to receive 80Gy from HDR alone and/or from 45Gy external beam (EB) plus 35Gy HDR.

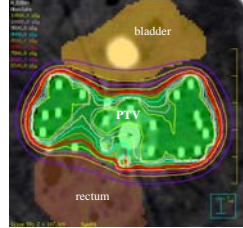
**Results:** The figures below compare isodose plans optimized with physical dose and biological effect (EUD)-based objective functions.

80Gy HDR-physical

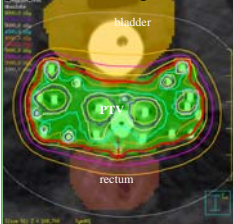


The physical dose-based plan is more uniform but shows lower TCP. The heavy red line is the 80Gy prescription isodose line.

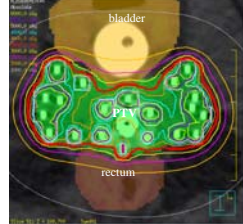
80Gy HDR-biological



45Gy EB+35Gy HDR physical dose optimization



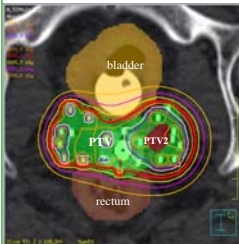
45Gy EB+35Gy HDR biological optimization



The difference between the two plans are reduced when HDR is used in conjunction with external beam. The red line represents 80Gy delivered by 45Gy external beam and 35Gy HDR treatments.

The table below summarizes dosimetric indices for the four plans illustrated above.

	80Gy HDR		45Gy EB + 35Gy HDR	
	Physical	Biological (EUD)	Physical	Biological (EUD)
CI	0.95	0.95	0.95	0.95
HI	0.72	0.60	0.70	0.42
OI	0.07	0.13	0.08	0.19
TCP	0.71	0.77	0.88	0.87
NTCP(Bladder)	0.00	0.00	0.02	0.02
NTCP(Rectum)	0.02	0.00	0.21	0.18
NTCP(Sigmoid)	0.00	0.00	0.17	0.13
EUD(Bladder), Gy	37.6	38.1	61.5	62.5
EUD(Rectum), Gy	51.5	42.5	65.8	64.8
EUD(Sigmoid), Gy	45.2	40.2	64.2	62.4
EUD(PTV), Gy	92.5	94.9	86.2	86.3



The algorithm takes into account the molecular imaging data during optimization. The example shows that higher dose is delivered to PTV2, which is assigned a clonogen cell density of  $2 \times 10^{11}$  per  $\text{cm}^3$  compared with  $2 \times 10^8$  at the rest of the PTV. This TCP/NTCP-based plan achieved TCP of 0.95 at PTV2 without significantly increase of NTCP (bladder 0.03, rectum 0.18, sigmoid 0.16). The plan is delivered by 45Gy external beam and 35Gy HDR to the red isodose line.

## Conclusions:

- ASA based optimization algorithm is potentially feasible for biological model-based HDR planning.
- Biology-based plans achieve better TCP/NTCP but are less uniform than that from physical model.
- Biological optimization may be more effective for HDR alone or HDR plus low external beam doses.