Dosimetric Impact of Hidden Input Parameters in Inverse Optimization Algorithms for GYN HDR Brachytherapy: A Systematic In-House Study

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ABSTRACT

Purpose: To quantify the dosimetric impact of hidden input parameters in two inverse optimization (IO) algorithms— Inverse Planning Simulated Annealing (IPSA) and Hybrid Inverse Planning Optimization (HIPO)—for GYN HDR brachytherapy, demonstrated using commercial tandem-and-ovoid applicator with needles.

Methods: In-house implementations of the IPSA and HIPO algorithms were developed and benchmarked against their corresponding implementations in a commercial treatment planning system. Forty-three clinical cases were evaluated using 245 combinations of internal optimization parameters. For IPSA, the investigated parameters included the maximum number of iterations, step size, and alpha. For HIPO, the investigated parameters included the maximum number of iterations, gradient-reduction tolerance, and objective-function-reduction tolerance. HRCTV D90%, V100, V200%, OAR D2cc were evaluated.

Results: For IPSA, a low maximum iteration and small step size were associated with increased dose heterogeneity and higher hot spots within the HR-CTV. These effects plateaued beyond 2e5 iterations and a step size of 0.1, respectively. Lower alpha values produced a pronounced increase in HR-CTV hot spots. For HIPO, higher gradient-reduction and objective-function-reduction tolerances resulted in earlier optimization termination, leading to increased HR-CTV hot spots but lower OAR D2cc.

Conclusions: Inverse-planning outcomes were sensitive to the selection of hidden optimization parameters. HR-CTV V150, HR-CTV V200, and OAR D2cc showed the greatest variability, whereas HR-CTV D90 and V100 were comparatively robust to deviations in parameter settings.

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INTRODUCTION

Inverse optimization algorithms are widely used in gynecologic high-dose-rate brachytherapy to improve target coverage while limiting dose to organs at risk. Comparisons among optimization methods have primarily focused on plan quality under user-defined dose objectives and constraints. However, the final solution also depends on internal algorithm settings that control the optimization process.

In commercial treatment planning systems, these internal parameters are generally inaccessible to users, and limited information is available regarding the extent to which variations in these settings affect clinically relevant dosimetric outcomes or whether their optimization could further improve plan quality. This study investigated the dosimetric effects of internal optimization parameters in IPSA and HIPO for gynecologic brachytherapy using in-house implementations that permitted direct control of the optimization settings.

METHODS AND MATERIALS

Search grid for parameters used for IPSA and HIPO are listed in Table 1. HR-CTV D90%, V100, V200%, D2cc for bladder, rectum, sigmoid, and bowel were evaluated for each combination.

Table 1 Hidden parameters used for IPSA and HIPO

IPSA						
Max Iteration	2.E+05	6.E+05	2.E+06	6.E+06	2.E+07	
Step Size	0.01	0.03	0.10	0.30	1.00	3.00
Alpha	0.00	0.10	0.30	0.60	1.00	3.00
HIPO						
Max iteration	10	30	100	300	1000	
Gradient reduction tolerance	1.E-03	3.E-03	1.E-02	3.E-02	1.E-01	3.E-01
Objective function reduction tolerance	1.E-04	3.E-04	1.E-03	3.E-03	1.E-02	3.E-02

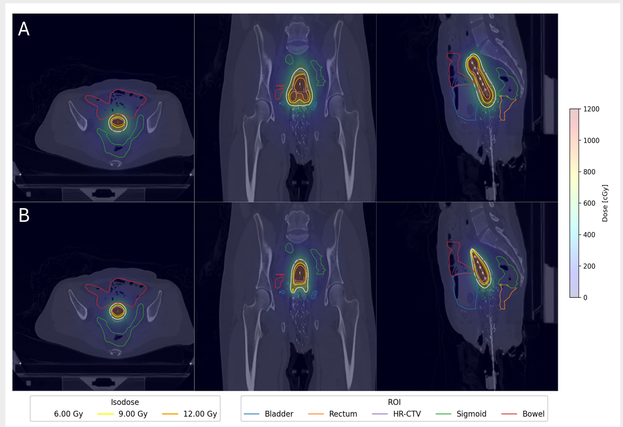

Figure 1 Example of two plans optimized using IPSA. A: max iteration = 2E5, step size = 0.1, alpha = 0.6; B: max iteration = 2E6, step size = 0.1, alpha = 0

RESULTS

Figure 1 shows two example plans optimized using IPSA with different hidden parameters combination. For IPSA, a low maximum iteration and small step size were associated with higher hot spots within the HR-CTV and reduced OAR D2cc (Figure 2). These effects plateaued beyond 2e5 iterations and a step size of 0.1, respectively. Lower alpha, which rejects less worse plans, produced a pronounced increase in HR-CTV hot spots (Figure 3). Simultaneous deviations in the maximum number of iterations, step size, and alpha produced cumulative effects, resulting in substantially greater HR-CTV hot spots, but also lower OAR doses.

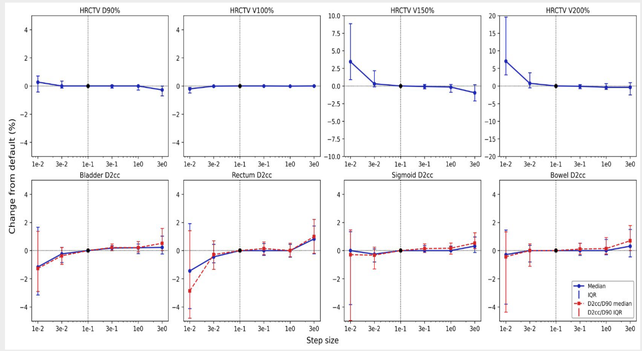

Figure 2 For IPSA, lower step size results in higher V150 and V200 in HR-CTV and lower OAR D2cc.

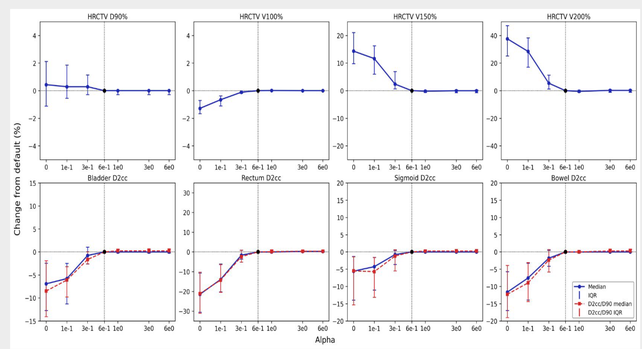

Figure 3 For IPSA, lower alpha results in higher V150 and V200 in HR-CTV and lower OAR D2cc.

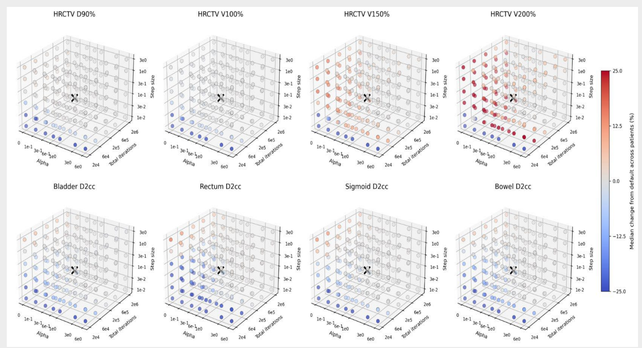

Figure 4 For IPSA, combined effect for max iteration, step size, and alpha.

Similar trends were observed for HIPO. A lower maximum iteration resulted in increased HR-CTV hot spots. However, HIPO converged with substantially fewer iterations than IPSA because it uses a gradient-based optimization approach rather than simulated annealing. Higher gradient-reduction and objective-function-reduction tolerances also promoted earlier termination, resulting in greater HR-CTV hot spots and lower OAR dose. Dose metrics change of all plans compared to baseline are shown in Figure 6.

DISCUSSION

The results demonstrate that internal optimization parameters can meaningfully alter the dosimetric trade-offs produced by inverse planning algorithms. In both IPSA and HIPO, selected parameter settings generated plans with lower OAR D2cc while largely preserving HR-CTV D90 and V100. This suggests that the default internal configurations in treatment planning systems may not represent the only clinically useful solution and that additional OAR sparing may be achievable through systematic tuning of hidden parameters. However, the reduction in OAR dose was frequently accompanied by increased dose heterogeneity within the target, as reflected by higher HR-CTV V150 and V200.

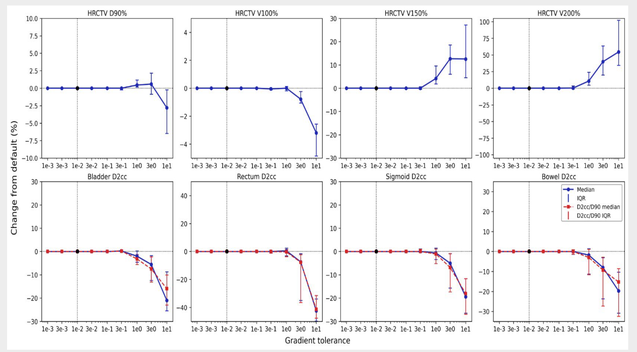

Figure 5 For HIPO, higher gradient-reduction tolerance results in higher V150 and V200 in HR-CTV and lower OAR D2cc.

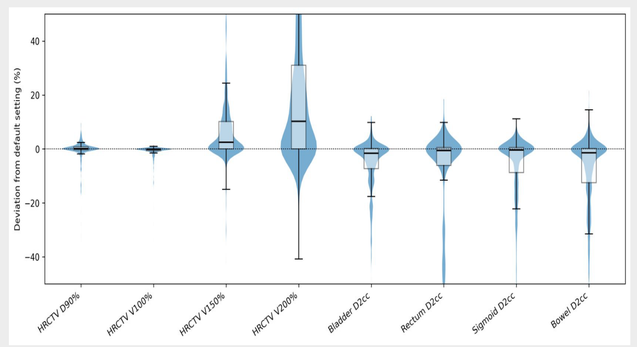

Figure 6 Dose metrics change of all plans compared to baseline.

CONCLUSIONS

Internal optimization settings represent an additional, underexplored degree of freedom in brachytherapy treatment planning. Rather than relying exclusively on defaults, systematic parameter selection may enable improved patient-specific trade-offs between target coverage, dose heterogeneity, and OAR sparing. Further investigation is needed to identify parameter ranges that provide clinically meaningful OAR reductions without producing unacceptable target hot spots.

REFERENCES

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2. Trnková et al, Radiotherapy and Oncology. 93, 331–340 (2009).