Robust Optimization for Gynecological High Dose Rate Interstitial Brachytherapy

Kai Jiang*, Rachel McCarroll, Michael MacFarlane, Naru Lamichhane, Pranshu Mohindra

Department of Radiation Oncology, University of Maryland, Baltimore, MD

*Contact: Kai.Jiang@umm.edu

INTRODUCTION

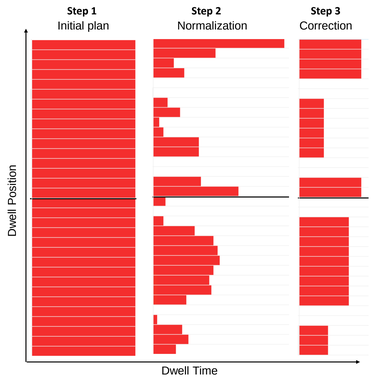
- Inverse planning is gaining increased popularity in high-dose-rate (HDR) brachytherapy due to the superior target volume coverage and normal tissue sparing achievable with inverse optimization.
- However, inverse planning often results in large variation in needle dwell times between adjacent dwell positions, which may increase the plan's susceptibility to needle displacement.
- In fact, it is not uncommon for needles to displace by several millimeters up to 2 cm.[1]

AIMS

- To propose a robust optimization technique that increases dwell time uniformity between neighboring dwell positions
- To demonstrate robustness of the generated plans to needle displacement, as compared to inversely optimized plans

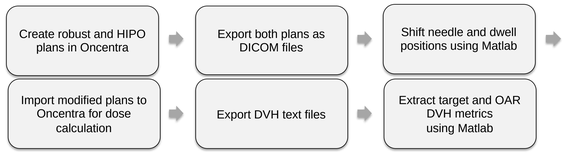
METHODS

- **Study subjects:** gynecological HDR cases using the Syed-Neblett template (n=9)
- **Treatment planning system:** Oncentra® Brachy
- **Treatment planning methods**
  - Inverse planning: hybrid inverse planning optimization (HIPO) [2]
  - Robust planning: a three-step forward planning technique



METHODS (CONTINUED)

- **Needle displacement** on 6 selected needles adjacent to bladder and rectum
  - Systematic displacement: retraction of all needles by 5 mm
  - Random displacement: following a normal distribution at 5±5 mm
- **HIPO vs. robust plans**
  - Comparisons
    - Target coverage and organ-at-risk (OAR) sparing at baseline
    - Changes in target coverage and OAR sparing by needle displacement
  - Dose volume histogram (DVH) metrics
    - Gross tumor volume (GTV): V100%, D100%, V150%, V90%, and D90%
    - High-risk target volume (HR-CTV): V100%, D100%, V150%, V90%, and D90%
    - Bladder and rectum: D2cc
- **Workflow**



RESULTS

- ***The robust plans, compared to the HIPO plans, showed less variations in dwell times of adjacent dwell positions along the same needle***

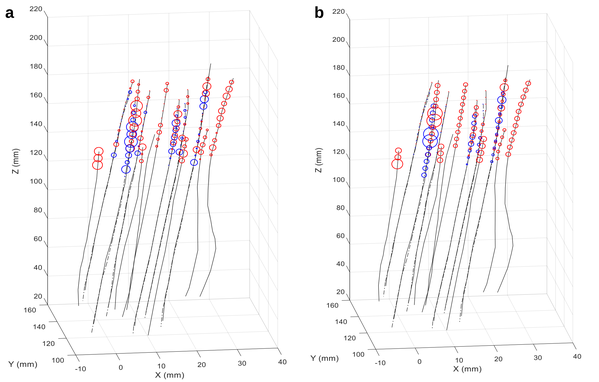


Figure 1. HIPO and robust plans. Representative HIPO (**a**) and robust (**b**) plans for the same patient. Black lines represent the needles, while the red and blue circles indicate the dwell positions at baseline and after needle displacement, respectively. The size of circle indicating the relative dwell weight. For each needle, the displacement is generated randomly following a normal distribution with both mean and standard deviation at 5mm. Note that the robust plan has smaller variations in dwell weights at adjacent dwell positions.

RESULTS (CONTINUED)

- ***At baseline, the robust and HIPO plans had similar DVH metrics for target coverage and OAR sparing***

Table 1. *The DVH metrics for HIPO and robust plans at baseline*

Volume	DVH Metric	HIPO Plan (%)	Robust Plan (%)	P Value
HRCTV (n=9)	V100%	92.7±4.2	92.1±4.4	0.06
	D100%	58.7±14.5	59.0±14.3	0.84
	V150%	52.8±6.8	51.9±7.8	0.22
	V90%	96.4±3.1	96.1±3.2	0.31
	D90%	104.8±7.0	103.6±7.2	0.06
GTV (n=4)	V100%	96.2±2.5	96.4±2.4	0.22
	D100%	66.6±17.3	70.6±14.8	0.36
	V150%	64.3±3.2	62.8±4.0	0.06
	V90%	98.0±1.8	98.4±1.8	0.14
	D90%	115.2±6.0	114.2±5.2	0.40
Bladder (n=9)	D2cc	83.2±7.4	83.8±6.7	0.26
Rectum (n=9)	D2cc	72.4±10.5	72.7±11.0	0.72

Note: P values calculated using Student's paired t-test.

- ***The robust plans showed improved GTV coverage with needle displacement***

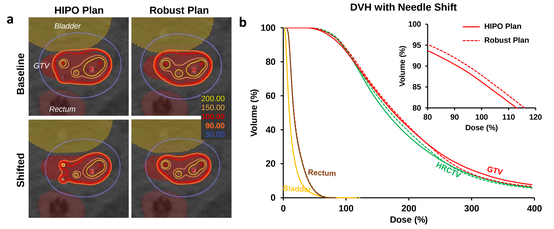


Figure 2. Improved GTV coverage by the robust plan compared to the HIPO plan with needle displacement. (**a**). Representative dose maps of the HIPO (left) and robust (right) plans at baseline (top) and after a 5-mm needle retraction (bottom). (**b**). DVH plots with needle displacement. A zoomed view is displayed to show the improved GTV coverage by the robust plan (dashed red curve), as compared to the HIPO plan (solid red curve).

- ***With systematic needle displacement, the robust plan offered 4.1% improvement in GTV D90***

Table 2. *Changes in DVH metrics by the systematic needle displacement*

Volume	DVH Metric	HIPO Plan (%)	Robust Plan (%)	P Value
HRCTV (n=9)	ΔV100	-2.1±1.6	-1.9±0.8	0.65
	ΔD100	-4.8±3.4	-3.5±4.5	0.31
	ΔV150	-1.6±1.8	-1.4±1.7	0.66
	ΔV90	-1.6±1.2	-1.4±0.8	0.57
	ΔD90	-4.2±3.3	-3.3±1.6	0.22
GTV (n=4)	ΔV100	-3.8±2.2	-2.9±2.1	**0.03**
	ΔD100	-8.1±2.8	-5.5±3.1	0.30
	ΔV150	-3.3±3.5	-2.4±7.2	0.69
	ΔV90	-2.6±2.0	-2.0±1.6	0.10
	ΔD90	-10.1±6.2	-6.0±6.4	**0.00**
Bladder (n=9)	ΔD2cc	-1.8±4.7	-2.5±5.6	0.31
Rectum (n=9)	ΔD2cc	-0.6±2.2	-0.4±2.5	0.66

Note: P values calculated using Student's paired t-test.

RESULTS (CONTINUED)

- ***With random needle displacement, the robust plan offered 3.1% improvement in GTV D90***

Table 3. *Changes in DVH metrics by the random needle displacement*

Volume	DVH Metric	HIPO Plan (%)	Robust Plan (%)	P Value
HRCTV (n=9)	ΔV100	-4.1±5.3	-3.7±3.7	0.55
	ΔD100	-3.9±7.3	-4.0±6.9	0.93
	ΔV150	-3.8±4.1	-3.4±2.9	0.54
	ΔV90	-3.0±4.7	-2.8±3.6	0.57
	ΔD90	-7.8±10.7	-6.6±7.9	0.26
GTV (n=4)	ΔV100	-6.8±8.4	-6.1±7.8	0.16
	ΔD100	-10.8±7.2	-10.4±8.5	0.72
	ΔV150	-6.6±5.3	-4.7±6.1	0.06
	ΔV90	-5.9±7.9	-5.2±7.3	0.08
	ΔD90	-17.1±18.1	-14.0±17.2	**0.05**
Bladder (n=9)	ΔD2cc	-2.7±8.2	-3.9±9.0	0.12
Rectum (n=9)	ΔD2cc	-1.4±2.6	-1.5±2.2	0.61

Note: P values calculated using Student's paired t-test.

DISCUSSION

- Inverse planning offers faster optimization in HDR planning, and typically completes within seconds
- Nevertheless, the generated inverse plans tend to be susceptible to needle displacement due to unnecessarily large variations in needle dwell times
- The proposed robust plan technique takes approximately 15 minutes. But with graphical optimization involved, planners have better control over the isodose distribution.
- More importantly, the generated plans have improved uniformity in needle dwell times, which significantly increases the robustness of these plans to needle displacement

CONCLUSIONS

- A robust planning technique for HDR brachytherapy is proposed
- Compared to inverse planning, robust planning offers more robust GTV coverage with needle displacement
- Further studies are needed to evaluate its clinical benefits to gynecological patients

REFERENCES

1. Rey F, Chang C, Mesina C, Dixit N, Kevin Teo BK, Lin LL. Dosimetric impact of interfraction catheter movement and organ motion on MRI/CT guided HDR interstitial brachytherapy for gynecologic cancer. Radiother Oncol. 2013 Apr;107(1):112-6.
2. A. Karabis, S. Giannouli, D. Baltas, "HIPO: A hybrid inverse treatment planning optimization algorithm in HDR Brachytherapy", Radiother. Oncol., 76, Supplement 2, 29, 2005.